Durable Wood Composites for Naval Low-Rise Buildings

Final Report

January 2007

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DURABLE WOOD COMPOSITES FOR NAVAL LOW-RISE BUILDINGS

FINAL REPORT

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Durable Wood Composites For Naval Low-Rise Buildings

Market Assessment

Siding and Trim Components

Task S1 - Evaluate the durability perceptions, WPC substitution potential, and reasons for adopting (purchasing and carrying) new building materials from key members of the value chain (building material wholesalers and retailers).

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Project End Report
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SUMMARY

Previous US Navy contract – N00014-00-C-0488:

Navy Public Works Officers (PWOs) & Resident Officers in Charge of Construction (ROICCs) - In an earlier study for the US Navy (under Contract N00014-00-C-0488; Naval Advanced Wood Composites – Timber Structure Inventory and Assessment), survey data was obtained for Task 2 (T2) from targeted Navy Public Works Officers (PWO's) and Resident Officers in Charge of Construction (ROICCs)[1] (n=89) at Naval facilities throughout the U.S. to examine wood construction durability issues, opportunities to substitute woodfiber-plastic composite components in various building material applications, benefits of adopting new building materials, and methods for communicating with these Navy specifiers. T2 results suggest that an effective strategy for diffusing new innovative woodfiber-plastic composite building materials into the US Naval construction market may include the following: "The promotion of durable, low risk, affordable, and environmentally friendly materials through conferences and workshops, trade shows, and trade journals featuring WPC molding, fencing, decking/railing, and siding/siding accessories."

Prime Contractors and Top 200 US Residential Builders - Under the same US Navy Contract in Task 4 (T4), survey data was obtained from both a census of "Prime" builders-contractors[2] (n=85) that serve the Navy and the top 200+ U.S. residential builders[3] (based on sales revenues) for civilian coastal community construction issues. T4 results suggest that effective strategies for diffusing new innovative woodfiber-plastic composite building materials through "Prime" contractors may include the following: "The promotion of durable, low risk, low liability materials through architects and trade journal publications featuring WPC siding/siding accessories, windows, fencing, and railings/decking." T4 results also suggest that effective strategies for diffusing new innovative woodfiber-plastic composite building materials through "Top 200+" builders may include the following: "The promotion of durable, low liability, low life cycle cost materials through wholesalers, and at trade shows featuring WPC decking/railings, door lineals, fencing and siding."

From these three T2 and T4 respondent groups, a subset of "opinion leaders" was formed based upon their relatively high self-rated knowledge of and experience with wood-fiber plastic composites. An effective strategy for diffusing new innovative woodfiber-plastic composite building materials through the study's "Opinion Leaders" may include the following: "The

[1] The 89 PWO and ROICC points of contact were obtained through 18 Liaison Officers.

[2] The "Prime" list (updated 01/02) compiled by NAVFAC includes all commercial/industrial prime contractors (defined as averaging at least $17 million in gross receipts over the last three years). These relatively large industrial builders are likely to be heavy users of building materials, and they are required by the Federal Acquisition Regulations (FAR) to subcontract to smaller firms. Firms matching the following criteria were included in the sample frame: (1) those that were involved in construction projects and use building materials (as opposed to those that have contracts for custodial, disposal services, or other non-building projects; and (2) those that serve both Navy and civilian coastal communities in the U.S.

[3] The Top 200+ list includes the 200 largest residential builders in the US (in 2001) plus the top 25 manufactured home builders plus the top 30 modular home builders. Deleting duplications resulted in a sample frame of 243 firms.

promotion of durable, low liability, low risk, affordable materials through trade journals, trade shows, and ads from material manufacturers featuring WPC siding/siding accessories, fencing decking, and door lineals."

Task S1 under Contract N00014-03-1-0949:

Top 200 Building Material Wholesalers and Retailers - Accordingly, this study under a new US Navy Contract (*N00014-03-1-0949*) followed a similar format and questionnaire structure to obtain comparable data from key members of the building materials value chain. The top 200 building material wholesalers and Top 200 building material retailers served as the population of interest.

Top 200 Wholesaler and Retailer respondents generated 84 percent and 77 percent of their revenues, respectively, from building materials. Wholesalers sourced 87 percent of their purchases direct from manufacturers and 8 percent from other stocking wholesalers and sold 45 percent of their merchandise to retailers, 30 percent direct to builders, and 10 percent to other wholesalers. Retail respondents sourced 35 percent of their merchandise direct from manufacturers, 30 percent from stocking wholesalers, 29 percent from buying coops, and 6 percent from non-stocking wholesalers. Our Retailers sold 79 percent of their merchandise to builders, 19 percent to homeowners/DIY'ers.

In general, Retail respondents adopted WPC's earlier and at a higher rate vs. Wholesalers and those respondents who adopted new products early – or "early adopters" (both Retail and Wholesale) placed more emphasis on supplier relationships and merchandise breadth vs. later adopters of WPC products. Retailers generally self-rated themselves as the most knowledgeable of and most experienced with WPC's vs. the other 4 populations in this study. Wholesale respondents rated themselves as second highest (of the 5 groups) on WPC knowledge and experience.

Wholesalers ranked moulding as having the highest WPC substitution potential, followed by RTA furniture, window lineals, exterior door framing, interior doors, deck boards/stair treads, and deck railing systems. Retailers ranked deck boards/stair treads highest, followed by deck railing, fascia/soffits/corners, exterior door framing, fencing, window lineals, RTA furniture, and siding.

Wholesalers place the greatest importance on current building materials suppliers as a source of information regarding new building materials followed by trade/industry journals (Pro Sales is #1), and trade show exhibits. Retailer respondents rated trade shows (NAWLA and NAHB are #1 and #2) as the most important source of new building material information, followed by current suppliers, their homeowner customers, and trade/industry journals (Pro Sales and Home Center News are #1 and #2).

Among Wholesale respondents, profit growth was the most important benefit associated with adopting new building materials followed by sales growth, and competitive pressures. For Retailers, profit growth was also the most important benefit followed by sales growth, relationship with suppliers, competitive pressures, and inventory turnover risks.

The full report (263 pp.) was delivered to the Navy project team as a final report in August, 2004 and may be found in the Appendix.

Categorize the best channel strategy for innovative new WPC materials

Channels for industrial infrastructure materials rely heavily on project specifications that may, or may not, be influenced by in-house or independent architects and engineers. This rather obscure process underscores the importance of understanding the appropriate mechanisms by which new industrial materials are communicated to the architectural and engineering community (both government and private). Demonstration projects, trade shows, and key trade journals and association newsletters are typically used to disseminate technical information to these scientific audiences.

In contrast, building materials distribution channels may include wholesale and/or retail intermediaries who provide the goods and services direct to builders or DIY (Do-It-Yourself) buyers. Two key, yet related, elements for successfully competing in US building materials markets are access to distribution channels and the ability to employ an effective communications mix strategy.

A favorable channel position, defined as the manufacturers' reputation among distributors for providing products, services, financial returns, support and incentive programs, and quick response systems (vis-à-vis competitors), is highly coveted for the significant competitive advantage and barrier to entry they represent. And an effective push-pull communication strategy is a key requisite for securing distribution contracts. Push promotion targets distributors with personal selling, favorable credit terms, a full product line, quick response systems (JIT, EDI, bar coding, etc.), coop advertising, sales contests, in-store POP (Point-of-Purchase) displays, trade show assistance, samples, and training programs. Pull promotion programs target the builder and homeowner with TV and magazine ads, trade/home shows, web-based information, and high-visibility showcase material demonstration projects. The synchronization of these push-pull promotional efforts creates impressions and excitement regarding the products or brand and thus strengthens the manufacturers' channel position.

Channel strategies have been described in the preceding sections for PWO's, ROICC's, "Prime" builders-contractors, and "Top 200" residential builders, wholesalers, and retailers. The following sections are taken from earlier studies for the US Navy under Contract *N00014-02-C-0385(recreation bridge decking) and N00014-97-C-0395(port authorities and marina owners/operators).*

Recreation Bridge Decking – Previous US Navy work (under contract N00014-02-C-0385) summarized the results from surveys of USDA-FS Regional Bridge Engineers, Professional Trailbuilders Association (PTBA) members, and Bridge Manufacturing firms in the

recreational bridge construction industry[4]. Specific promotional strategy recommendations from these studies may include the following: An overall message from manufacturers and/or channel intermediaries that emphasizes Long-Life, Low Maintenance, and Life-Cycle Cost would be appropriate; Durability and The Environment were perceived as strong points for WPCs, whereas Strength and Aesthetics were problem areas – and should be addressed; Word of Mouth (Vendors and Peers), Seminars/Conferences, and the Internet are the best vehicles for promoting new products to these three trailbridge specifiers

The earlier US Navy research also provides a summary of survey results targeting Private U.S. A&E firms in the recreational bridge construction industry[5]. Specific promotional strategy recommendations may include: An overall message emphasizing Low Maintenance, Decay Resistance and Initial Cost; Low Maintenance and Decay Resistance were perceived as strong points for WPCs, whereas Chemical Free and Thermal Expansion were problem areas – and should be addressed; and the Internet and Trade/Industry Journals are the best vehicles for promoting new products to these key specifiers.

Marina Owners and Operators - Also under US Navy contract N00014-02-C-0385, Steven R. Shook summarized the results from surveys marina owners and operators in the US[6]. Specific promotional strategy recommendations from this study are as follows: Waterfront construction materials were most frequently purchased from retailers (67%) followed by wholesale distributors (49%), and manufacturer agents (33%). The importance of product samples as well as the advantages of experiencing a new WPC construction material first hand through demonstrations was repeatedly stressed. Personal selling was the most effective communication tool followed by advertising. Trade publications and magazines are viewed as both the primary and the most effective sources of advertising used marina owners and operators to learn about new products. Beyond advertising, trade shows and product samples were the two most important sources of information to learn about waterfront construction materials, followed by demonstrations and websites.

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[4] McGraw, D.F. and P.M. Smith. 2005. Opportunities for Woodfiber-Plastic Composites in the US Recreational Bridge Market. Presentation at and abstract in the 8th International Conference on Woodfiber-Plastic Composites. May 23-25, 2005. Madison, WI. USA. See also McGraw, D.F. 2005. Opportunities for Wood-Plastic Composites in the Recreational Bridge Decking Market**.** Unpublished Master's Thesis, Penn State Univ.

[5] McGraw, D.F. and P.M. Smith. 2005. The Influence of US Architectural and Engineering Firms in the Recreational Bridge Material Decision. Presentation at the 8th International Conference on Woodfiber-Plastic Composites. May 23-25, 2005. Madison, WI. USA. See also McGraw, D.F. 2005. Opportunities for Wood-Plastic Composites in the Recreational Bridge Decking Market. Unpublished Master's Thesis, Penn State Univ

[6] Shook, S.R. 2005. Profile of the distribution structure for materials used in waterfront applications: implications for innovative wood-plastic composites. Project end report for *Commercialization of Navy Advanced Woood Composites, Task M2 – Waterfront Material Alternatives – Products, Channels, and Communications.* Prepared for Office of Naval Research under contract N00014-02-C-0385. Oct. 50pp.

***Industrial Waterfront Materials* –** In previous US Navy research (under contract N00014-97-C-0395) conducted in 1999 and 2000, three nationwide surveys of decision-makers at the nation's port authorities[7] (n=165), engineering consulting firms[8] (n=95), and marinas[9] (n=11,045) indicated a need for waterfront materials and products with superior performance capabilities having a combination of "ideal" attributes that may not be currently available in the marketplace[10]. In particular, these industrial market studies showed that waterfront building materials and products are performance driven (reliable strength, & decay resistance) and that the primary cost drivers are life-cycle and maintenance costs as opposed to initial costs. However, these same three industrial infrastructure specifier groups ranked wood lower on performance attributes (strength, long-life, durability) vs. concrete and composites and better on low cost (viewed as less expensive). These findings underscore the perilous position of treated wood materials and products that are currently used in waterfront infrastructure applications and lend credence to the viability of new composite products with superior value propositions for these markets.

Recommendations/Conclusions:

Innovative WPC building materials may be sold in a variety of ways, depending on the specific end-use application, the degree of customization, and the necessary technical information that must accompany the product. Residential building materials may require code compliance and are often used by builders and homeowners. These materials are typically procured direct from retail or wholesale suppliers. However, very large builders may opt to buy direct from a manufacturer.

Industrial infrastructure materials are generally specified by a project owner or operator, an independent project architectural engineering firm, and/or a government architect or engineer. These materials are generally more customized and can be sold either through a wholesaler or direct from the manufacturer to the end user. In some circumstances, residential products may be suitable for an industrial application; these products may be stocked by wholesale and/or retail building material distributors.

Appropriate distribution strategies must be combined with the necessary communications message and medium, and these strategic variables must be tailored to the specific product, application, and end-use audience in order to provide the greatest chance for success.

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[7] Represents those US Port Authorities listed in the American Association of Port Authorities (Mihaiu 1998).

[8] Represents those US engineering consulting firms listed in the American Association of Port Authorities (Mihaiu 1998) and involved in waterfront infrastructure projects in 1999.

[9] Includes all US marinas listed in the 1999 National Marina Directory published by the National Marine Manufacturers Assn., Chicago, IL.

[10] Smith, P.M. and K.D. Bright. 2002. Perceptions of new and established waterfront materials: US port authorities and engineering consulting firms. Wood & Fiber Sci., 34(1):28-41. Bright, K.D. and P.M. Smith. 2002. Perceptions of new and established waterfront materials by US Marina Decision Makers. Wood & Fiber Sci., 34(2):186-204.

Durable Wood Composites For Naval Low-Rise Buildings

Market Assessment

Task S1 – Evaluate the Durability Perceptions, WPC Substitution Potential, and Reasons for Adopting (purchasing and carrying) New Building Materials from Key Members of the Value Chain (building material wholesalers and retailers).

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ABSTRACT

In an earlier study for the US Navy (under ***Contract N00014-00-C-0488; Naval Advanced Wood Composites – Timber Structure Inventory and Assessment***), survey data was obtained for Task 2 (T2) from targeted Navy Public Works Officers (PWO's) and Resident Officers in Charge of Construction (ROICCs)[1] (n=89) at Naval facilities throughout the U.S. to examine wood construction durability issues, opportunities to substitute woodfiber-plastic composite components in various building material applications, benefits of adopting new building materials, and methods for communicating with these Navy specifiers. T2 results suggest that an effective strategy for diffusing new innovative woodfiber-plastic composite building materials into the US Naval construction market may include the following: "The promotion of durable, low risk, affordable, and environmentally friendly materials through conferences and workshops, trade shows, and trade journals featuring WPC molding, fencing, decking/railing, and siding/siding accessories."

Under the same US Navy Contract in Task 4 (T4), survey data was obtained from a census of "Prime" builders-contractors[2] (n=85) that serve the Navy. In addition, the top 200+ U.S. residential builders[3] (based on sales revenues) served as the sample frame to address civilian coastal community construction issues. T4 results suggest that effective strategies for diffusing new innovative woodfiber-plastic composite building materials through "Prime" contractors may include the following: "The promotion of durable, low risk, low liability materials through architects and trade journal publications featuring WPC siding/siding accessories, windows, fencing, and railings/decking." Also in T4, results suggest that effective strategies for diffusing new innovative woodfiber-plastic composite building materials through "Top 200+" builders may include the following: "The promotion of durable, low liability, low life cycle cost materials through wholesalers, and at trade shows featuring WPC decking/railings, door lineals, fencing and siding."

From the three T2 and T4 respondent groups, a subset of "opinion leaders" was formed based upon their relatively high self-rated knowledge of and experience with wood-fiber plastic composites. An effective strategy for diffusing new innovative woodfiber-plastic composite building materials through the study's "Opinion Leaders"

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Accordingly, this study under a new US Navy Contract (*N00014-03-1-0949*) followed a similar format and questionnaire structure to obtain comparable data from key members of the building materials value chain. The top 200 building material wholesalers and Top 200 building material retailers served as out population of interest. The results are contained in this document and comparisons to the other three populations of interest are provided.

Our Wholesaler and Retailer respondents generated 84 percent and 77 percent of their revenues, respectively, from building materials. Wholesalers sourced 87 percent of their purchases direct from manufacturers and 8 percent from other stocking wholesalers and sold 45 percent of their merchandise to retailers, 30 percent direct to builders, and 10 percent to other wholesalers. Retail respondents sourced 35 percent of their merchandise direct from manufacturers, 30 percent from stocking wholesalers, 29 percent from buying coops, and 6 percent from non-stocking wholesalers. Our Retailers sold 79 percent of their merchandise to builders, 19 percent to homeowners/DIY’ers.

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INTRODUCTION

Materials science advancements related to composite technologies are ongoing, and composite product lines for building applications are evolving. Potentially high-volume end-uses exist within the construction industry (Ashley 1996, Black 1998, Westrup 1992). In particular, usage of wood fiber plastic composite building products is estimated to increase 50% each year for the next five years (PATH 2000). Businesses and individuals differ in their openness to new ideas and technologies (Mitropoulos and Tatum 2000). The construction industry is generally perceived as conservative in adopting new technologies (Koebel 1999; Mitropoulos and Tatum 1999).

LITERATURE REVIEW

Innovation, Adoption, and Diffusion

The innovation, adoption and diffusion of new products, defined as the process by which an innovation "is communicated through certain channels over time among the members of a social system" (Rogers 1995) has been the subject of considerable research since innovation diffusion theory was introduced into marketing in the 1960s (Arndt 1967; Baptista 1999; Bass 1969; Mahajan et al. 1990; Rogers 1995). The degree to which target consumers perceive the new product to have a relative advantage compared to the product it supersedes is more important to the actual rate of adoption and new product success than any "objective" advantage the new product may have (Rogers 1995). Understanding the propensity of contractor groups to accept technological solutions to construction issues is crucial to developing new products with customer-orientations based on those factors considered most significant to the end-user and therefore, with the greatest opportunity for success in the marketplace.

Adopter/Innovativeness Categorization Schemes

Rogers proposed one of the most widely accepted categorization schemes (1962, 1971, 1985, 1995) and other categorization schemes in the literature are related to this one. Based on evidence from investigations of innovations in a variety of settings, Rogers identified five adopter categories (innovators, early adopters, early majority, late majority, and laggards) that follow a bell-shaped normal distribution. Articulating the justification for the normal distribution of adopter categories, he writes (1983, p. 244)

> *…we expect normal adopter distribution because of the diffusion effect, defined…as the cumulatively increasing degree of influence upon an individual to adopt or reject an innovation, resulting from the activation of peer networks about the innovation in the social system. This influence results from the increasing rate of knowledge and adoption or rejection of the innovation in the system. Adoption of a new idea is the result of human interaction through interpersonal networks. If the first adopter of the innovation discusses it with two other members of a social system, and each of these two adopters passes the new idea along to two peers, the resulting distribution*

follows a binomial expansion, a mathematical function that follows a normal shape when plotted over a series of successive generations.

Using basic statistical parameters of the normal distribution—mean time of adoption (t) and its standard deviation (Φ) the five categories are defined as shown in table 1 (Table 1).

TABLE 1. Rogers' Innovation Diffusion Adopter Categories (Rogers 1995)

Adopter Category	***% adopters***	***Area covered under normal curve***
Innovators	2.5	Beyond t - 2Φ
Early Adopters	13.5	Between t - Φ and t - 2Φ
Early Majority	34.0	Between t and t - Φ
Late Majority	34.0	Between t and t + Φ
Laggards	16.0	Beyond t + Φ

Innovators in this classification are estimated to be the first 2.5% to adopt an innovation within a social system, whereas laggards are the last 16% to adopt.

Strengths of the categorization scheme proposed by Rogers are (1) it is easy to use, (2) it offers mutually exclusive and exhaustive standardized categories so that results can be compared, replicated, and generalized across studies, and (3) given the underlying diffusion curve is assumed to be normal, continued acceptance of the product can be predicted and linked to adopter categories (Mahajan et al. 1990). However, in spite of its theoretical appeal, the assumption that all new products' diffusion patterns follow a normal distribution is questionable.

Peterson (1973) argues new product adoption patterns are likely to exhibit non-normal distributions. Using adoption dates as a one-dimensional ordered vector, Peterson suggests partitioning these data into *k* mutually exclusive contiguous groups such that the within-group sum of squares is minimized and, simultaneously, the among-groups sum of squares is maximized. The number of groups *k* can be varied until no significant incremental change in within-group sum of squares is observed. However using Peterson's method, the results are situation-specific or data dependent and different numbers and sizes of adopter categories might be obtained for the same innovation, depending on the length of adoption time-series data used to develop the categories. Replications and comparisons are limited. (See Mahajan and Peterson 1985 for additional review of other adopter distributions.)

Midgley (1977) argues that for marketing purpose the categorization scheme should allow for the summed percents of innovators (2.5 percent) and early adopters (13.5 percent) as the best definition of earlier adopters (16 percent). The prime reason for this is practical: most studies focus on the innovators, and if these are defined as 2.5 percent of the adopting population it is necessary to contact a very large number of respondents in order to locate a statistically significant number of innovators.

Despite variations in terminology and specific definitions of adopter categories, the underlying importance of developing marketing communication strategies based on an understanding of the most influential innovators is widely recognized in diffusion and adoption literature. For example, Barczak et al. (1992) found that sales promotion tools, such as trade shows should be adapted to adopter categories to be successful. Early product adopters who attend trade shows differ from other adopter categories with respect to their objectives for attendance and the importance of post-show activity; they seek more specific information and use more retail as opposed to media sources (e.g. television advertisements) for post-show information. In addition to adopter categories, an understanding of the innovation diffusion process is important in developing new product marketing communication strategies.

Innovation Decision Process and Potential Adopters

Diffusion is the process by which an innovation is communicated through certain channels over time among the members of a social system (1995). The importance of communication among potential adopters is central to the theme of adoption and diffusion literature. In his most recent conceptual model (1995), the five components of the innovation decision process are knowledge, persuasion, decision, implementation, and confirmation (Figure 1).[4]

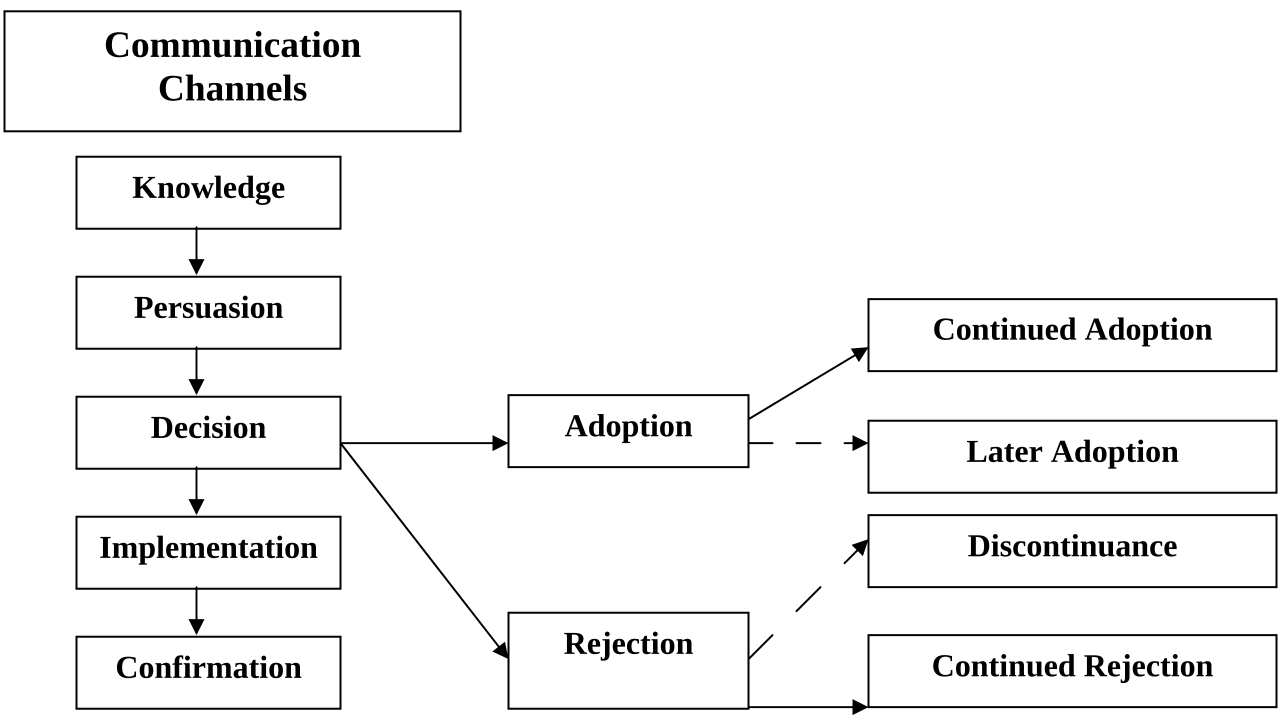

Figure 1. Elemental components of Rogers' refined model of innovation diffusion process *(Adapted from Rogers, 1995)*

[4] Rogers' initial conceptual model assumes that an individual progresses through five basic stages: awareness, interest, evaluation, trial and adoption/rejection. Rogers substantially refined his original model to capture the various outcomes that were obtained in other diffusion research and to highlight the importance of the communication process among innovators and potential adopters.

The first stage of the innovation diffusion process occurs when a potential adopter obtains knowledge of an innovation. Knowledge can range from simple exposure to the innovation's existence to general information acquisition to better understand the innovation. The information sought by potential adopters during this stage seeks to bridge the gap between perceived expectations and the actual performance of the innovation. During the persuasion stage the potential adopter seeks evaluative information concerning advantages and disadvantages of the new product in order to develop a favorable or unfavorable attitude toward the innovation. Communication with opinion leaders, peers, or others who have already tried the innovation is sought. Trial use of the innovation may be employed if possible. During the implementation stage, the adopter puts the innovation to use and may seek to modify the innovation to suit a particular need. During the last stage, confirmation or reinforcement of the innovation decision is sought. It is interesting to note that the state of the adoption decision is not considered permanent. In other words, the adopting unit may reverse the decision to adopt if exposed to conflicting messages about the innovation. Reassessment of the adoption decision is ongoing.

The relationship of these stages to adopter categories, and in particular to the innovators, is tied to the effect communication plays in the adoption of a new product.

Midgley (1977, p.70) explains the importance in this way:

> *It has already been stated that the innovators perform a vital role in the diffusion of an innovation in that they effectively test the new product, and it is on the basis of their findings that other individuals adopt or not. The innovators' initial perception of the product is modified by their experience of its actual performance, and it is this perception, favorable or unfavorable, which is relayed to others via interpersonal communication.*

Marketing communication strategies should be designed to reduce uncertainty throughout the diffusion process and should be targeted to specific stages of the diffusion process to be more successful. For example, during the knowledge stage potential adopters have increased awareness for the new product and may be reached through mass media. However, in the later stages more specialized and interpersonal forms of communication may be required, especially with more technologically complex innovations (Shook 1997).

In addition, interpersonal communication may reduce uncertainty throughout the diffusion process. Two primary forms of interpersonal communications that may reduce uncertainty through the stages of the innovation diffusion process are termed the "demonstration effect" (Mansfield 1961) and the word-of-mouth effect (Bass 1969). As greater numbers adopt a new technology, the uncertainty of its value diminishes as non-adopters benefit from the experience of past adopters (Davis 1979), new usages are discovered, and word-of-mouth supplements advertising (Bass1969). However, if the new product does not live up to the market's expectations, the

demonstration effect could negatively impact on the probability of adoption (Kalish and Lilien 1986; Dockner and Jorgensen 1988).

The individual characteristics of the potential adopter that influence the innovation diffusion process have also been studied at great length (Antil1988; Baptista 1999; Blackeley and Shepard 1996; Mahajan et al. 1990). Socioeconomic characteristics, personality variables, and communication behaviors have been shown to differ for innovators. Innovators tend to be involved in large interpersonal social networks, have a higher degree of mass media exposure, and are able to cope with a higher degree of uncertainty (Rogers 1995). However, the diffusion process is more complex when applying it to organizational decision-making rather than to individual decision-making.

Organizations and the Innovation Diffusion Process

Rogers' model for the innovation diffusion process for organizations consists of initiation, decision-making and implementation in a sequence of five stages, each of which is characterized by a range of events, actions, and decisions. These five stages are agenda setting, matching, redefining and restructuring, clarifying, and routinizing (figure 2).

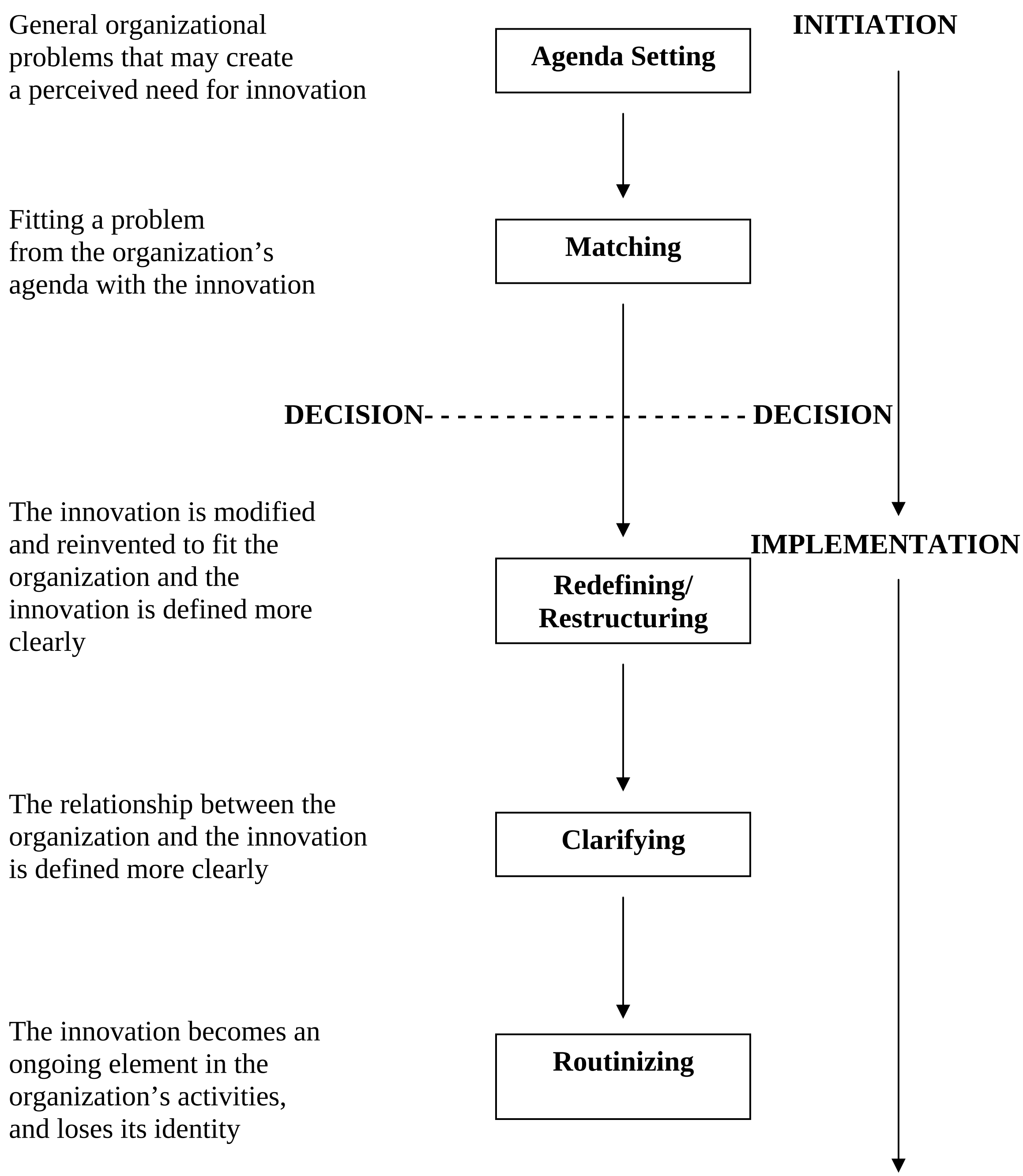

Figure 2. Elemental components of Rogers' refined model of innovation diffusion process for organizations *(Adapted from Rogers, 1995)*

The model of innovation diffusion process for organizations accommodates decision systems that involve more than one decision-maker.[5] During the agenda setting

[5] The literature on industrial purchasing stresses that many people are involved in the purchasing decision process (Kohli 1989; Crow and Linquist 1985; Ghingold 1985; Spekman and Stern 1979; Sheth 1973; Lehmann and O'Shauhnessy 1974).

stage the organization searches for potential innovations that will solve the problem. The matching stage involves one of the organizational problems identified in the agenda setting stage with an appropriate innovation. Next, in the redefining/restructuring stage the innovation is modified or refitted to meet a particular organization's needs. The innovation is put to use in the clarifying stage, where it is evaluated and either modified or rejected. And finally, in the routinizing stage, the innovation becomes part of the ongoing organizational activities and is no longer viewed as an innovation.

Much of the literature on adoption and diffusion has focused on the organizational characteristics that influence innovativeness. Some of the factors influencing the degree of innovativeness that appear most frequently in the literature include leadership (Hage and Dewar 1973); centralization (Zmud 1982); size (Rose and Joskow 1990); risk aversion (Lattin and Roberts 1988); information processing capabilities (Jensen 1988); decision-maker information processing characteristics (Gatignon and Robertson 1989). Again, conflicting results for the factors influencing the degree of organizational innovativeness appear. For example, firm size is one of the most effective predictors of innovativeness with larger firms being more likely to adopt new technologies first (Damanpour 1987; Hannan and McDowell 1984; Kimberly and Evanisko 1981). Yet Nabseth and Ray (1974) report several cases of a negative impact of size on firms' innovativness.

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INNOVATION, ADOPTION, AND DIFFUSION FINDINGS

At this stage, as a tie-in to the literature review on innovation, adoption, and diffusion, the following analysis will provide insight:

Opinion Leaders

"Opinion Leaders" were determined through respondent's relatively high self-rating of BOTH THEIR EXPERIENCE WITH & KNOWLEDGE OF WPC's (rated as 3, 4 or 5 on a 6-point scale from 0-5; n=19/74 [25%]). The breakdown per population in the study is as follows:

- •LNO's (n=6=32%) (6/37=16% of LNO's)
- •Prime (n=5=26%) (5/14=36% of Prime)
- •Top 200 (n=8=42%) (8/23=35% of Top 200)

General findings are as follows:

> Opinion Leaders were more influential in the selection and purchase of building materials. Deckboards/railings, roofing, floor underlayment, fencing, and exterior door framing were applications perceived as least durable (most durability problems). Siding/siding accessories, decking/railing, fencing, exterior door framing, and molding were the applications perceived to have the greatest potential for WPC substitution. Building material wholesalers, trade shows, trade journals, and ads by material manufacturers were the best sources of new product information. And, durability, reduced liability, reduced risk, affordability and aesthetics were the primary benefits driving the adoption of new innovative building materials by this group of opinion leaders.

The following tables show the responses of the Opinion Leaders compared to the rest of the respondents for the following:

- Role in Selection of New Building Materials
- Role in Purchase of New Building Materials
- Durability Perceptions
- Substitution Potential
- Communication Methods
- Perceived Benefits of Adopting New Building Materials

Role in Selection of New Building Materials

	Role in Selection of New Building Materials Know & Exp >=3								
	0 - No Influence	1	2	3	4	5 - Much Influence	N	Mean	Std. Deviation
Total	1		2	1	7	7	18	3.89	1.37
LnO			1	1	2	2	6	3.83	1.17
Prime	1		1		2	1	5	3.00	2.00
"Top 200"					3	4	7	4.57	0.53

Table 1 – Role in Selection of New Building Materials – Opinion Leaders

	Role in Selection of New Building Materials Know or Exp <3								
	0 - No Influence	1	2	3	4	5 - Much Influence	N	Mean	Std. Deviation
Total	3	5	6	10	16	11	51	3.25	1.48
LnO	3	3	5	5	9	4	29	2.90	1.57
Prime		2	1	3	3		9	2.78	1.20
"Top 200"				2	4	7	13	4.38	0.77

Table 2 – Role in Selection of New Building Materials – All Others

Role in Purchase of New Building Materials

	Role in Purchase of New Building Materials Know & Exp >=3								
	0 - No Influence	1	2	3	4	5 - Much Influence	N	Mean	Std. Deviation
Total	3		3	2	5	5	18	3.17	1.79
LnO	2			2	1	1	6	2.50	2.07
Prime	1		3		1		5	2.00	1.41
"Top 200"					3	4	7	4.57	0.53

Table 3 – Role in Purchase of New Building Materials – Opinion Leaders

	Role in Purchase of New Building Materials Know or Exp <3								
	0 - No Influence	1	2	3	4	5 - Much Influence	N	Mean	Std. Deviation
Total	8	10	5	7	11	10	51	2.65	1.80
LnO	8	10	3	2	3	3	29	1.69	1.69
Prime				4	4	1	9	3.67	0.71
"Top 200"			2	1	4	6	13	4.08	1.12

Table 4 – Role in Purchase of New Building Materials – All Others

Durability Perceptions

All Respondents - Knowledge and Experience >= 3						All Others	
Building Component	**N**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**	**N**	**Mean**
I joists	19	2	5	4.00	0.88	49	4.27
Beams/headers	18	3	5	3.89	0.76	49	4.24
Roof trusses	19	2	5	3.84	0.83	48	4.10
Sill plates	19	2	5	3.74	0.81	49	3.63
Moldings	19	2	5	3.63	0.76	49	3.73
Fascia, soffit, corners	19	2	5	3.53	0.84	49	3.31
Kitchen cabinets	19	2	4	3.53	0.61	49	3.69
Window lineals	18	2	5	3.50	0.71	47	3.60
Bathroom cabinets	19	2	4	3.42	0.77	48	3.71
Wall Framing	18	1	5	3.39	1.14	48	3.90
Siding	18	2	4	3.33	0.69	48	3.38
Roof sheathing	19	2	4	3.26	0.73	49	3.49
Interior doors	19	1	4	3.21	0.85	49	3.61
Exterior door framing	19	1	5	3.16	0.90	48	3.23
Deck railing systems	19	2	4	3.16	0.83	48	3.23
Fencing	16	2	4	3.13	0.81	47	3.21
Floor underlayment	19	2	4	3.11	0.74	48	3.69
Roofing	18	1	5	3.06	1.26	49	2.86
Deck boards/stair treads	18	2	4	3.06	0.73	49	3.24

Table 5 – Durability Perceptions – Opinion Leaders vs. All Others

Substitution Potential

All Respondents - Knowledge and Experience >= 3						All Others	
Building Component	**N**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**	**N**	**Mean**
Fascia, soffit, corners	18	3	5	4.22	0.73	43	3.12
Fencing	17	2	5	4.18	0.81	45	3.40
Deck railing systems	17	3	5	4.12	0.70	46	3.43
Siding	19	2	5	4.11	0.99	44	3.09
Exterior door framing	19	2	5	3.95	0.97	44	2.77
Molding	18	1	5	3.83	1.20	45	3.42
Deck boards/stair treads	18	1	5	3.67	1.19	48	3.46
Sill plates	18	0	5	3.67	1.46	42	2.67
Interior doors	19	1	5	3.53	0.96	44	3.02
RTA Furniture	14	1	5	3.50	1.02	38	3.11
Window lineals	13	0	5	3.38	1.56	42	2.81
Bathroom cabinets	19	0	5	3.11	1.29	42	2.52
Roofing	17	1	5	3.06	1.14	39	2.10
Floor underlayment	19	1	5	2.95	1.35	44	2.59
Kitchen cabinets	19	0	5	2.95	1.43	42	2.50
Beams/headers	17	0	5	2.76	1.56	43	1.88
Roof sheathing	18	1	5	2.67	1.46	40	2.45
Wall Framing	18	0	5	2.67	1.61	41	2.02
Roof trusses	18	0	5	2.56	1.72	41	1.88
I joists	17	0	5	2.53	1.62	42	1.83

Table 6 – Substitution Potential – Opinion Leaders vs. All Others

Communication Methods

All Respondents - Knowledge and Experience >= 3						All Others	
Communication Factor	**N**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**	**N**	**Mean**
Current Building Material Suppliers	8	2	5	4.25	1.16	12	3.92
Trade/industry journals	19	2	5	3.74	0.93	49	3.31
Trade show exhibits	19	0	5	3.53	1.65	49	3.35
Ads from material mfgrs	19	0	5	3.47	1.35	49	3.00
Opinions of peers	19	0	5	3.42	1.26	49	3.65
Customers (homeowners)	8	1	5	3.13	1.46	12	2.83
Conferences/seminars	19	0	5	3.11	1.59	49	3.39
Government research	19	0	5	2.84	1.46	49	2.61
Direct mail	19	0	5	2.68	1.63	48	2.60
Media promotion	19	0	5	2.21	1.62	48	2.10
Other - Arch. Specs	1	5	5	5.00	0.00	-	-
Other - Salesman/Distribution	1	5	5	5.00	0.00	-	-
Other - Use Spec. Matl.	1	5	5	5.00	0.00	-	-

Table 7 – Communication Methods – Opinion Leaders vs. All Others

Perceived Benefits of Adopting New Building Materials

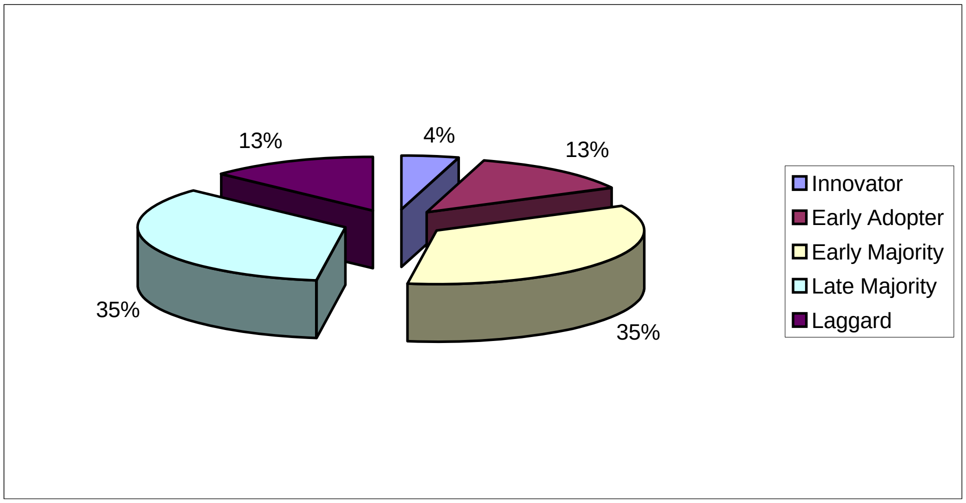
All Respondents - Knowledge and Experience >= 3						All Others	
Perceived Benefit	**N**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**	**N**	**Mean**
Durability	19	3	5	4.58	0.69	51	4.33
Reduced liability	19	3	5	4.42	0.77	50	3.64
Safety (reduced risk)	19	1	5	4.16	1.12	51	4.00
Affordability	19	3	5	4.05	0.91	51	4.06
Aesthetics	19	2	5	3.95	0.85	51	3.65
Ease of installation	19	2	5	3.79	0.85	51	3.86
Environmentally friendly	19	0	5	3.47	1.58	51	3.35
Other -Historic Preservation	1	5	5	5.00	0.00	-	-
Other - Customer Requested	1	5	5	5.00	0.00	-	-

Table 8 – Perceived Benefits – Opinion Leaders vs. All Others

Adoption & Diffusion of New Innovative Building Materials

Table 9 breaks down the study's "Top 200+" respondents according to Rogers' Innovation Diffusion Adopter Categories (Rogers 1995). Only these "Top 200+" respondents completed a construct asking for their level of agreement/disagreement on a 7-point scale regarding 12 statements

Adopter Category	***% adopters***	***Area covered under normal curve***
Innovators	2.5	Beyond t - 2Φ
Early Adopters	13.5	Between t - Φ and t - 2Φ
Early Majority	34.0	Between t and t - Φ
Late Majority	34.0	Between t and t + Φ
Laggards	16.0	Beyond t + Φ



Adopter Categories	Shared Characteristics
Innovators	2.5%. Require a shorter adoption period than any other group. Venturesome, mobile, daring. Risk takers. Financial Resources to absorb unprofitable innovations, understand and apply complex technical knowledge to cope with a high degree of uncertainty.
Early Adopters	13.5%. Upward social mobility. Greatest degree of opinion leadership, role model within social system, respected by peers, successful.
Early Majority	34%. Interacts frequently with peers, seldom holds positions of opinion leadership, deliberate before adopting a new idea.
Late Majority	34%. Responds to pressure from peers, economic necessity, skeptical, cautious.
Laggards	16%. No opinion leadership. Isolated. Point of reference is the past. Suspicious of innovations, innovation decision process is lengthy, resource limited.

Table 9 – Adopter Categories of "Top 200+" US Builders Based on Rogers' Diffusion of Innovation Theoretical Model

Company Diffusion of Innovation Statements – "Top 200+" Builders, Wholesalers, & Retailers

Respondents in the "Top 200+" Builders, Wholesalers, and Retailers populations were asked whether they agree or disagree (1 = strongly disagree to 4 = neutral to 7 = strongly agree) with certain statements concerning new product adoptions. They agreed most with the statement "Like to Use New Products" (mean = 4.92) and agreed least with "Slow to Detect Industry Shifts" (mean = 2.58).

Statement	N	1 - Strongly Disagree	2	3	4 - Neutral	5	6	7 - Strongly Agree	Mean	Std. Dev.
My company would like to use a new product today, if possible.	91		11	6	25	12	11	26	4.92	1.71
My company is oriented more toward the future than the present.	92	2	5	14	16	22	16	17	4.82	1.59
We are likely to be one of the first companies to use a new product.	91	7	7	17	15	13	14	18	4.47	1.88
My company likes to experiment with new ways of doing things.	92	7	7	14	17	19	13	15	4.45	1.79
My company finds it difficult to change established construction procedures to cater to the needs of a new product.	91	8	8	11	20	21	17	6	4.24	1.68
My company likes to take chances with new products.	92	17	14	15	15	13	7	11	3.63	1.97
My company can easily change our building practices to fit the needs of a new product.	91	7	23	14	24	10	9	4	3.55	1.61
Our current marketing abilities are not very useful in marketing homes that use new products.	91	13	24	13	24	7	5	5	3.25	1.66
Our relationships with current suppliers are more important than using new products.	92	11	28	21	17	7	5	3	3.09	1.52
Many of our building practices cannot be applied to new products.	91	11	30	10	29	7	3	1	3.04	1.39
New products are usually gimmicks.	92	15	28	17	17	7	7	1	2.98	1.53
My company is slow to detect fundamental shifts in our industry (e.g., competition, technology, regulation).	92	23	32	12	16	4	5		2.58	1.42

Table 10 – Diffusion of Innovation Statements Agreement, Total

Statement	N	1 - Strongly Disagree	2	3	4 - Neutral	5	6	7 - Strongly Agree	Mean	Std. Dev.
My company is oriented more toward the future than the present.	23	1	1	1	3	4	6	7	5.35	1.70
My company would like to use a new product today, if possible.	23		3	2	8	2	1	7	4.74	1.79
My company finds it difficult to change established construction procedures to cater to the needs of a new product.	23	2		4	8	1	7	1	4.35	1.61
My company likes to experiment with new ways of doing things.	23	3		4	4	7	2	3	4.30	1.79
We are likely to be one of the first companies to use a new product.	23	2	1	7	4	2	3	4	4.22	1.88
My company can easily change our building practices to fit the needs of a new product.	23	1	5	1	6	4	4	2	4.17	1.75
Our current marketing abilities are not very useful in marketing homes that use new products.	23	3	4	3	8	1	1	3	3.65	1.85
New products are usually gimmicks.	23	3	5	5	4	3	3		3.35	1.61
Our relationships with current suppliers are more important than using new products.	23	1	7	10	1	2	2		3.09	1.31
Many of our building practices cannot be applied to new products.	23	4	8	3	5	2	1		2.83	1.44
My company likes to take chances with new products.	23	8	2	5	5	1	1	1	2.83	1.75
My company is slow to detect fundamental shifts in our industry (e.g., competition, technology, regulation).	23	5	10	4	2	1	1		2.43	1.31

Table 11 – Diffusion of Innovation Statements Agreement, “Top 200+” Builders

Statement	N	1 - Strongly Disagree	2	3	4 - Neutral	5	6	7 - Strongly Agree	Mean	Std. Dev.
My company would like to use a new product today, if possible.	29		4	2	5	2	5	11	5.21	1.86
We are likely to be one of the first companies to use a new product.	28	1	3	5	3	5	1	10	4.82	1.98
My company likes to experiment with new ways of doing things.	29	1	2	5	4	5	6	6	4.79	1.76
My company is oriented more toward the future than the present.	29	1	3	5	3	7	7	3	4.55	1.68
My company finds it difficult to change established construction procedures to cater to the needs of a new product.	28	2	3	3	8	7	2	3	4.18	1.66
My company likes to take chances with new products.	29	3	5	6	1	7	2	5	4.03	2.01
My company can easily change our building practices to fit the needs of a new product.	28	1	6	6	10		3	2	3.68	1.56
Our relationships with current suppliers are more important than using new products.	29	4	7	4	7	2	3	2	3.45	1.80
Many of our building practices cannot be applied to new products.	28	1	10	3	10	2	1	1	3.32	1.42
Our current marketing abilities are not very useful in marketing homes that use new products.	28	5	7	3	7	3	1	2	3.25	1.78
New products are usually gimmicks.	29	3	12	5	6	2		1	2.86	1.38
My company is slow to detect fundamental shifts in our industry (e.g., competition, technology, regulation).	29	8	11	3	5	1	1		2.41	1.35

Table 12 – Diffusion of Innovation Statements Agreement, Wholesalers

Statement	N	1 - Strongly Disagree	2	3	4 - Neutral	5	6	7 - Strongly Agree	Mean	Std. Dev.
My company would like to use a new product today, if possible.	39		4	2	12	8	5	8	4.82	1.55
My company is oriented more toward the future than the present.	40		1	8	10	11	3	7	4.70	1.42
We are likely to be one of the first companies to use a new product.	40	4	3	5	8	6	10	4	4.38	1.82
My company likes to experiment with new ways of doing things.	40	3	5	5	9	7	5	6	4.28	1.83
My company finds it difficult to change established construction procedures to cater to the needs of a new product.	40	4	5	4	4	13	8	2	4.23	1.76
My company likes to take chances with new products.	40	6	7	4	9	5	4	5	3.80	1.96
My company can easily change our building practices to fit the needs of a new product.	40	5	12	7	8	6	2		3.10	1.45
Our current marketing abilities are not very useful in marketing homes that use new products.	40	5	13	7	9	3	3		3.03	1.44
Many of our building practices cannot be applied to new products.	40	6	12	4	14	3	1		2.98	1.35
New products are usually gimmicks.	40	9	11	7	7	2	4		2.85	1.58
Our relationships with current suppliers are more important than using new products.	40	6	14	7	9	3		1	2.83	1.38
My company is slow to detect fundamental shifts in our industry (e.g., competition, technology, regulation).	40	10	11	5	9	2	3		2.78	1.54

Table 13 – Diffusion of Innovation Statements Agreement, Retailers

When comparing the agreement with the statements concerning new product adoptions between the individual populations it is seen that their perceptions are statistically significantly different based on a 0.10 significance level using ANOVA for the following statements: “Likes to Take Chances with New Products” and “Easily Change Building Practices”.

Statement	Total	"Top 200"	Wholesalers	Retailers	Sig.
My company would like to use a new product today, if possible.	4.92	4.74	5.21	4.82	0.552
My company is oriented more toward the future than the present.	4.82	5.35	4.55	4.70	0.167
We are likely to be one of the first companies to use a new product	4.47	4.22	4.82	4.38	0.479
My company likes to experiment with new ways of doing things.	4.45	4.30	4.79	4.28	0.456
My company finds it difficult to change established construction procedures to cater to the needs of a new product.	4.24	4.35	4.18	4.23	0.936
My company likes to take chances with new products.	3.63	2.83	4.03	3.80	**0.067**
My Company can easily change our building practices to fit the needs of a new product	3.55	4.17	3.68	3.10	**0.032**
Our current marketing abilities are not very useful in marketing homes that use new products.	3.25	3.65	3.25	3.03	0.355
Our relationships with current suppliers are more important then using new products.	3.09	3.09	3.45	2.83	0.244
Many of our building practices cannot be applied to new products.	3.04	2.83	3.32	2.98	0.415
New products are usually gimmicks.	2.98	3.35	2.86	2.85	0.411
My company is slow to detect fundamental shifts in our industry (e.g., competition, technology, regulation).	2.58	2.43	2.41	2.78	0.506

Table 14 – Comparison of Diffusion of Innovation Statements Agreement

Theoretical Classification of "Top 200+" Survey Data

To further explore the process of adoption in this exploratory research, we assigned a score based on 100 points to each respondent according to their responses to the diffusion of innovation statements. We then used this score along with Rogers' Diffusion of Innovation theory to classify the respondents into adopter categories. The scores along with the number of products adopted pre respondent and the average number of adoptions per adopter category can be seen in the Table 15.

Classification[1]	Score[2]	Number of Products Adopted	Average Adoptions
Innovator	94	12	12
Early Adopter	80	6	5.67
Early Adopter	77	8	
Early Adopter	76	3	
Early Majority	73	2	5.75
Early Majority	71	2	
Early Majority	69	7	
Early Majority	69	6	
Early Majority	68	6	
Early Majority	67	9	
Early Majority	67	7	
Early Majority	67	7	
Late Majority	64	6	5.13
Late Majority	63	6	
Late Majority	60	6	
Late Majority	58	7	
Late Majority	58	4	
Late Majority	56	5	
Late Majority	56	4	
Late Majority	55	3	
Laggard	54	4	4.33
Laggard	51	4	
Laggard	26	5	

[1]Classification based on Rogers' Diffusion of Innovation Theory (1960).

[2]Score based on 100 points per statement after ranking.

Table 15 – Ranking of Diffusion of Innovation Statements for Adopter Classification based on Rogers' Diffusion of Innovation Theoretical Model

After assigning a category to each respondent we compared the perceptions of the categories for: 1) agreement with diffusion of innovation statements, 2) importance of communication factors in learning about new building materials, 3) importance of perceived benefits in adopting new building materials, 4) durability perceptions, and 5) substitution potential of WPC's for specific building applications.

Innovation Statements by "Top 200+" Adopter Categories

As can be seen in Table 16, the adopter categories had significantly different responses to 50% (6/12 = 50%) of the diffusion of innovation statement agreement construct (Table 12). This would lead us to believe that the different categories of adopters have differing opinions of their companies' adoption of new building materials.

Statement	Total	Innovator	Early Adopter/ Early Majority	Late Majority/ Laggard	Sig.
My company is oriented more toward the future than the present.	5.35	7.00	6.09	4.45	**0.038**
My company would like to use a new product today, if possible.	4.74	7.00	5.36	3.91	**0.063**
My company finds it difficult to change established construction procedures to cater to the needs of a new product.	4.35	4.00	3.91	4.82	0.427
My company likes to experiment with new ways of doing things.	4.30	7.00	4.91	3.45	**0.042**
We are likely to be one of the first companies to use a new product.	4.22	7.00	5.27	2.91	**0.001**
My company can easily change our building practices to fit the needs of a new product.	4.17	6.00	5.00	3.18	**0.021**
Our current marketing abilities are not very useful in marketing homes that use new products.	3.65	1.00	3.18	4.36	0.108
New products are usually gimmicks.	3.35	1.00	3.18	3.73	0.250
Our relationships with current suppliers are more important than using new products.	3.09	2.00	2.82	3.45	0.383
Many of our building practices cannot be applied to new products.	2.83	1.00	2.73	3.09	0.377
My company likes to take chances with new products.	2.83	7.00	3.09	2.18	**0.016**
My company is slow to detect fundamental shifts in our industry (e.g., competition, technology, regulation).	2.43	1.00	2.09	2.91	0.186

Table 16 – Diffusion of Innovation Statements Agreement by Adopter Categories

"Top 200+" Adopter Categories by Communication Factors, Perceived Benefits of Adopting New Building Materials, Durability Perceptions, and WPC Substitution Potential

Table 17 shows that the adopter categories are more alike when it comes to their opinions on the importance of communication factors in learning about new building materials. They had significantly different responses for 33% (3/10 = 33%) of the factors. This could lead to further exploratory research to help understand how to better reach the companies that adopt products before other companies to help speed up the processes of adoption and diffusion of new building materials.

Factor	Total	Innovator	Early Adopter/ Early Majority	Late Majority/ Laggard	Sig.
Current Building Material Suppliers	4.05	5.00	4.10	3.91	**0.010**
Trade Show Attendance	3.59	5.00	3.30	3.73	0.230
Opinions of Peers	3.27	3.00	3.10	3.45	0.469
Trade/Industry Journals	3.09	4.00	3.20	2.91	0.326
Advertisements of Material Manufacturers	2.95	4.00	2.90	2.91	**0.077**
Customers	2.95	4.00	2.60	3.18	0.610
Conferences/Seminars	2.68	5.00	1.90	3.18	**0.012**
Direct Mail	2.55	4.00	3.00	2.00	0.678
Government Research	1.77	3.00	2.00	1.45	0.544
Media Promotion	1.68	5.00	1.70	1.36	0.515

Table 17 – Importance of Communication Factors in Learning About New Building Materials by Adopter Categories

Table 18 shows that there is no significant difference among the adopter categories about the importance of perceived benefits in adoption new building materials. This information can still be useful because it shows that the groups have more uniform opinions about what they look for in new products meaning that products can be marketed by highlighting the attributes that are perceived to be beneficial to these builders.

Perceived Benefit	Total	Innovator	Early Adopter/ Early Majority	Late Majority/ Laggard	Sig.
Durability	4.48	5.00	4.55	4.36	0.708
Reduced Liability	4.48	5.00	4.55	4.36	0.740
Affordability	4.26	5.00	4.55	3.91	0.155
Safety (reduced risk)	4.17	5.00	4.09	4.18	0.794
Aesthetics	4.13	5.00	4.36	3.82	0.247
Ease of Installation	4.13	5.00	4.36	3.82	0.247
Environmentally Friendly (Green)	3.13	5.00	3.18	2.91	0.448

Table 18 – Importance of Perceived Benefits in Adopting New Building Materials by Adopter Categories

Table 19 shows that there is no significant difference between the adopter categories in terms of their durability perceptions of different building components.

	ADOPTER CATEGORY									Total			
	Innovator			Early Adopter/Early Majority			Late Majority/Laggard						
Building Component	Mean	N	Std. Dev.	Mean	N	Std. Dev.	Mean	N	Std. Dev.	Mean	N	Std. Dev.	Sig.
I -joists	5.00	1	.	4.45	11	0.69	4.27	11	0.47	4.39	23	0.58	0.453
Roofing	5.00	1	.	3.27	11	1.19	4.00	11	0.77	3.70	23	1.06	0.124
Roof Sheathing	4.00	1	.	3.55	11	0.82	3.82	11	0.98	3.70	23	0.88	0.737
Floor Underlayment	4.00	1	.	3.27	11	0.90	3.91	11	0.94	3.61	23	0.94	0.270
Interior Doors	4.00	1	.	3.55	11	0.52	3.91	11	0.54	3.74	23	0.54	0.266
Exterior Door Framing	3.00	1	.	2.64	11	1.29	3.45	11	0.93	3.04	23	1.15	0.256
Fascia, Soffit, & Corners	5.00	1	.	3.36	11	1.36	3.55	11	1.04	3.52	23	1.20	0.445
Sill Plates	4.00	1	.	4.00	11	0.63	3.82	11	0.87	3.91	23	0.73	0.851
Kitchen Cabinets	4.00	1	.	4.00	11	0.45	4.00	11	0.77	4.00	23	0.60	1.000
Moldings	5.00	1	.	3.82	11	0.40	3.82	11	0.60	3.87	23	0.55	0.105
Beams/Headers	5.00	1	.	4.50	10	0.53	4.36	11	0.67	4.45	22	0.60	0.585
Roof Trusses	5.00	1	.	4.10	10	0.57	4.36	11	0.67	4.27	22	0.63	0.331
Window Lineals	4.00	1	.	3.70	10	0.67	3.82	11	0.75	3.77	22	0.69	0.884
Siding	3.00	1	.	3.18	11	1.17	3.50	10	1.35	3.32	22	1.21	0.820
Deck Boards/Stair Treads	4.00	1	.	3.36	11	0.81	3.30	10	0.95	3.36	22	0.85	0.752
Bathroom Cabinets	4.00	1	.	4.00	11	0.45	4.00	10	0.82	4.00	22	0.62	1.000
Wall Framing	5.00	1	.	3.27	11	1.01	3.78	9	0.97	3.57	21	1.03	0.206
Deck Railing Systems	4.00	1	.	3.18	11	1.17	3.33	9	0.71	3.29	21	0.96	0.722
Fencing	4.00	1	.	3.44	9	0.88	3.00	8	1.51	3.28	18	1.18	0.635

Table 19 – Durability Perceptions by Adopter Categories

Table 20 shows that there is a significant difference in the opinions of WPC substitution potential for the following building components: Moldings, Roof Sheathing, and I-joists.

	ADOPTER CATEGORY												
	Innovator			Early Adopter/Early Majority			Late Majority/Laggard			Total			
Building Component	Mean	N	Std. Dev.	Mean	N	Std. Dev.	Mean	N	Std. Dev.	Mean	N	Std. Dev.	Sig.
Deck Boards/Stair Treads	5.00	1	.	3.44	9	1.67	4.20	10	1.48	3.90	20	1.55	0.462
Deck Railing Systems	5.00	1	.	3.33	9	1.32	4.20	10	1.48	3.85	20	1.42	0.311
Exterior Door Framing	5.00	1	.	3.89	9	0.78	3.60	10	1.26	3.80	20	1.06	0.448
Fencing	5.00	1	.	3.63	8	0.92	3.63	8	1.77	3.71	17	1.36	0.647
Siding	5.00	1	.	3.44	9	1.01	3.67	9	0.87	3.63	19	0.96	0.317
Moldings	1.00	1	.	4.00	9	1.00	3.33	9	1.22	3.53	19	1.26	**0.055**
Fascia, Soffit, & Corners	5.00	1	.	3.33	9	1.58	3.22	9	1.48	3.37	19	1.50	0.555
Sill Plates	5.00	1	.	2.89	9	1.69	3.56	9	1.24	3.32	19	1.49	0.345
Interior Doors	4.00	1	.	3.11	9	1.17	3.33	9	1.00	3.26	19	1.05	0.719
Window Lineals	1.00	1	.	3.33	6	1.37	2.88	8	1.55	2.93	15	1.49	0.370
Ready-to-Assemble (RTA) Furniture	3.00	1	.	2.60	5	1.14	3.25	4	1.26	2.90	10	1.10	0.727
Roofing	5.00	1	.	2.00	5	1.41	2.63	8	1.06	2.57	14	1.34	0.118
Floor Underlayment	3.00	1	.	1.89	9	1.17	3.00	9	1.50	2.47	19	1.39	0.229
Roof Sheathing	5.00	1	.	1.88	8	1.25	2.50	8	0.93	2.35	17	1.27	**0.050**
Bathroom Cabinets	2.00	1	.	2.22	9	1.20	2.25	8	1.28	2.22	18	1.17	0.982
Wall Framing	3.00	1	.	2.13	8	1.89	2.14	7	1.57	2.19	16	1.64	0.892
Beams/Headers	1.00	1	.	1.75	8	1.28	2.63	8	1.77	2.12	17	1.54	0.421
I-joists	1.00	1	.	1.29	7	0.95	2.75	8	1.49	2.00	16	1.41	**0.096**
Kitchen Cabinets	1.00	1	.	2.00	9	1.22	2.13	8	1.46	2.00	18	1.28	0.735
Roof Trusses	1.00	1	.	1.38	8	1.60	2.63	8	1.41	1.94	17	1.56	0.240

Table 20 – Substitution Potential by Adopter Categories

Theoretical Classification of Distributor & Retailer Survey Data

While significant research has been conducted in the areas of new product adoption, manufacturer-channel relationships, and organizational purchasing, very little research has explored the role channel intermediaries play in the success of new product introduction (Aggarwal and Cha, 1997). The channel plays a particularly important role in the building materials industry where channels are typically quite long, and where power within the channel is undergoing considerable consolidation. Using an adaptation of Roger's classification of adopters, one of this study's main frameworks looks at the differences in companies involved in early or late adoption of products being introduced to the channel (Rogers, 1962).

We examined the adoption of WPC products by wholesalers and retailers in the building materials distribution channel and explored factors associated with early and late adopters of WPC products. This has led to the following:

1) Retailers have tended to adopt WPC in greater numbers than wholesalers, particularly in later years, indicating a faster adoption cycle in the retail setting as seen in Figure 1.

2) Early adopters placed more importance on supplier relationship and merchandise breadth when considering new product adoption, than did late and non-adopters as seen in the table below.
3) Adopters can be characterized as buying within the channel and selling to professional markets. See Figure 2 and Figure 3.

Factor	Early Adopter[b]	Late Adopter	Non-Adopter
Profit Growth	4.64	4.16	4.41
Sales Growth	4.36	4.26	3.82
Relationship With Suppliers	4.04*	3.74	3.10*
Competition	3.96	4.05	3.45
Inventory Turnover Risks	3.67	3.58	3.73
Inventorying and Storage Costs	3.64	3.11	3.55
Increasing Merchandise Breadth	3.46*	2.56*	3.00
Material Handling Processes	3.39	2.95	3.05

[a] Importance measured on a 5-point scale, where 5 = Critically important and 0 = No importance.
[b] Early and late adopter categories were created using a median-split based on year of adoption (Median = 1998, 1998 included in late adopter category)
* Significantly different at $\alpha = .05$

Table 21 – Importance of Operational Factors to the New Product Adoption Decision[a]

RESEARCH METHODOLOGY

LNO's

Sampling and Sampling Procedures

Discussions with NFESC indicated the appropriate sample frame for coastal structure populations are Navy personnel with building material usage experience. Specifically, personnel who are involved in maintenance and repair of facilities, construction administration, and specifying and selecting construction materials were sought. Navy-Marine Corps Liaison officers (LnOs) are most likely to be able to provide contact information for individuals at their facilities for each of the three categories. Although developing contact information for the target population using LnOs is a process that required additional time (development of an e-mailed form, cover letter, and a pretest of the form prior to administration, and time for responses to be received), it was determined to be the most accurate method to secure contact information on Navy personnel with the type of building experience necessary to render the data collected from the survey to be useful and applicable.

In March, 2002, *Timber Structures Inventory and Assessment Progress Report 2*, P. Smith and K. Bright cooperated with NFESC (Naval Facilities Engineering Service Center) to administer a research instrument, *Navy-Marine Corps Liaison Team: Request for Points of Contact* (See Appendix 1) to LNO's throughout the US. The request was attached to an emailed cover letter asking for contact names, titles, phone #'s, and email addresses of potential Naval building material purchasers and/or specifiers throughout the US.

The population contact list was provided by Theresa Hoffard, NFESC Research Chemist. Eighteen Liaison Officers, LnO's, recommended a total of eighty-nine people within their geographical areas to receive the survey. A copy of the email letter delivered to LnO's requesting their assistance in this effort is attached in Appendix 1. The final population contact list appears in Appendix 2. Response rates for this survey are discussed later in this report.

Data Collection

Studies have shown that questionnaires are the most effective means of data collection from a geographically dispersed population (Blankenship et al. 1992; Dillman 1978). A research instrument, *Material Usage and Building Application Survey*, was developed in cooperation with NFESC (Naval Facilities Engineering Service Center) and administered by NFESC. The survey research instrument was designed to identify additional candidates for wood-based materials, to provide basic material usage trends for building components, and to generate data that can be employed to identify specific benefits associated with the adoption of new building components. Additional questions solicited

information about demographics, selection and purchasing influence, and communication channel information.

The final version of the survey, as administered by NFESC in 2002, appears in Appendix 5. The last completed survey was received by Pennsylvania State University personnel on September 5, 2002. Personnel from PSU have coded and analyzed the questionnaire data. The results of that preliminary analysis are contained in this report.

Major Naval facilities within the United States are listed on the U.S. Navy website at http://www.chinfo.navy.mil/navpalib/bases/navbases.html. Figure 4 is a map from that web site illustrates the locations of Naval bases within the United States.

For purposes of this study, regions by state are delineated as follows (see Figure 5):
Southwest: CA, NV
Northwest: WA
Pacific: HI
South: TX, LA, MS, GA, FL, SC, TN
Atlantic: VA, MD, DC, PA
Northeast: RI, ME, CT, NJ

Based on response rates in the Northwest and Northeast (one response from each region), the Northwest region is combined with the Pacific region, and the Northeast region is combined with the Atlantic region for analysis of survey results.

Response Rates

The overall response rate was 41.6 percent. The survey population consisted of ninety Naval employees from Naval bases across the United States. Thirty-seven *Material Usage and Building Application* surveys were returned. Appendix A lists the survey population and highlights respondents.

Surveys were completed in all of the Navy regions identified for this study. Of the thirty-seven surveys returned, the greatest response from one region was 37.8 percent (n=14/37) in the Southwest region, followed by 24.3 percent (n=9/37) in the South region, 18.9 percent (n=7/37) in the Atlantic region, 8.3 percent (n=5/37) in the Pacific region, and 2.7 percent (n=1/37) in the Northwest and the Northeast. See Figure 6.

Higher overall response rates in the Southwest and South regions correlate to the higher number of Naval officers from those regions in the population selected to receive the *Material Building and Usage Application* surveys. Response rates *within* regions are depicted in Figure 7.

Study Bias

This study may have bias due to the relatively small sample sizes and minimal geographic representation. However, the findings of this exploratory research are useful to better understand the launching and marketing of successful new products.

Prime Contractors

Sampling and Sampling Procedures

A census of Prime Contractors involved in construction served as the main sample frame for "builder/contractor groups that serve Navy and Civilian coastal communities." Contact information for the Prime Contractors group included the most recent list (updated 01/02) compiled by NAVFAC listing all commercial/industrial prime contractors (defined as averaging $17 million in gross receipts over the last three years). In particular, firms matching the following criteria were included in the study:

1.) Those that are involved in construction projects and <u>use building materials</u> (as opposed to firms that have contracts for custodial, disposal services, or other non-building projects).

2.) Those that serve Navy and civilian coastal communities <u>in the U.S</u>.

Data Collection

In order to personalize the mailings to achieve a higher response rate, and to ensure the appropriate person in the firm received the survey, telephone calls to all firms included in this study were made in the spring of 2002 to verify the contact information from NAVFAC, and to obtain the name of the potential respondent (the primary decision-maker in the selection and purchase of building materials).

Data collection efforts began after the contact information had been verified. (For a timeline of these efforts see Table 22.) A pre-notification postcard was mailed on June 21st informing contacts of the imminent arrival of the questionnaire. On June 28th the first questionnaire was sent, with a cover letter explaining the purpose of the study and other instructions including descriptions of the two incentives to respond (entry into a prize drawing and a summary of the findings of the study). A reminder postcard was mailed July 8th. A second questionnaire was mailed on July 12th, with a cover letter requesting participation from non-respondents. After these efforts 7 completed questionnaires were received. The original population of 96 contractors was reduced for undeliverable surveys and surveys that were not applicable to the company, resulting in an adjusted population of 91 contractors, and an adjusted response rate of 7.7 percent.

Date	***Action***
Spring	phone calls for contact names
June 21st	pre-notification postcards mailed
June 28th	first questionnaire mailed
July 8th	reminder postcard mailed
July 12th	second questionnaire mailed
Aug 6th-Sept 16th	phone calls to remind or to get contact name for next mailing
Sept 25th	third questionnaire mailed

Table 22 – Timeline of Data Collection Efforts

Phone calls were made to all non-respondents to remind them about the questionnaire or to receive better contact information for subsequent mailings. It was extremely difficult to reach people, as summer is a very busy time of year for these companies. Messages were left with a contact phone number if they had any questions regarding the survey. At the end of this process only 2 more questionnaires had been returned and 2 additional companies claimed the survey was not applicable to them. Several duplicate records were also found in the original database.

In another effort to increase the response rate a third questionnaire was mailed September 25th with an added incentive to respond: each envelope contained a small gift for the respondent.

Response Rates

The overall response rate was 16.5 percent. The survey population consisted of 85 Prime Contractors that serve the Navy. Fourteen *Study of New Materials for Building Applications* surveys were returned.

14 responses
96 in original population
- 3 not applicable (one mailed, two from phone calls)
- 4 undeliverable (bad addresses)
- 4 duplicate records in the original database
85 contractors in reduced population
14/85 * 100 = 16.5% response rate prior to third mailing

Table 23 – Responses and Response Rates

Study Bias

This study may have bias because of the small sample sizes along with the low response rates. Also, it is biased more to the large end of the builder community. This exploratory research provides useful findings for launching and marketing a successful new product.

"Top 200+" Builders

Sampling and Sampling Procedures

The Prime Contractor group is also involved in civilian building projects. However, to augment the Navy – civilian comparisons, we have developed a database of the "Top 200+" Builders. This population consisted of builders from four separate lists on the Builder Online website (www.builderonline.com): 1) The BUILDER 100 Database (2001), 2) The Next 100 (2001), 3) 2001 Top 25 Manufactured Home Builders, and 4) 2001 Top 30 Modular/Whole House Panel Builders. There were two companies tied for number 200 on The Next 100 and twelve common builders between the Manufactured Home Builders and Modular/Whole House Panel Builders resulting in a total population of 244 builders.

Data Collection

Data collection efforts began in the fall of 2002. Surveys were sent to the top 200 builders with leaders in modular and manufactured houses added for a total mailing list of 244 (lists from Builder Online website). On November 11th the first questionnaire was sent, with a cover letter explaining the purpose of the study and other instructions including descriptions of the two incentives to respond (entry into a prize drawing and a summary of the findings of the study). A reminder postcard was mailed November 19th. A second questionnaire was mailed on December 2nd, with a cover letter requesting participation from non-respondents. After these efforts 23 completed questionnaires were received. The original population of 244 was reduced by one undeliverable survey, resulting in an adjusted population of 243 builders, and an adjusted response rate of 9.5 percent.

Response Rates

The overall response rate was 9.5 percent. The survey population consisted of the top 200 Builders plus leaders in the modular and manufactured housing industries for a total of 244 builders from across the United States. One survey was undeliverable for a final adjusted population of 243 builders. Twenty-three *Study of New Materials for Building Applications* surveys were returned.

Other similar surveys of builders have resulted in similar response rates (ranging from 6-12%). Builders represent a notoriously difficult group to survey.

Study Bias

This study may have bias because of the small sample sizes along with the low response rates. Also, it is biased more to the large end of the builder community. This exploratory research provides useful findings for launching and marketing a successful new product.

Wholesalers

Sampling and Sampling Procedures

A mail survey of the top 200 building materials wholesalers was conducted in November of 2002. This census population was selected due to its importance to building material supply, the top 25 companies accounts for approximately 56% of the wholesale market (U.S. Census Bureau and Home Channel News, 2002)®. This list was derived with the help of lists compiled by the Chain Store Guide and was based on business classification and annual sales in 1998 for wholesalers.

Data Collection

Data collection efforts began in the fall of 2002. On November 11th the first questionnaire was sent, with a cover letter explaining the purpose of the study and other instructions including descriptions of the two incentives to respond (entry into a prize drawing and a summary of the findings of the study). A reminder postcard was mailed November 19th. A second questionnaire was mailed on December 2nd, with a cover letter requesting participation from non-respondents. After these efforts 32 completed questionnaires were received. The original population of 200 was reduced by 26 undeliverable surveys and three surveys that were not applicable, resulting in an adjusted population of 171 wholesalers, and an **adjusted response rate of 18.7 percent**.

Response Rates

The overall response rate was 18.7 percent. There were three surveys that were not applicable and 26 undeliverable surveys. There were 32 responses from the adjusted population of 171.

Study Bias

This study may have bias because of the small sample sizes along with the low response rates. Also, it is biased more to the large end of the wholesale community. This exploratory research provides useful findings for launching and marketing a successful new product.

Retailers

Sampling and Sampling Procedures

A mail survey of the top 200 building materials retailers was conducted in November of 2002. This census population was selected due to its importance to building material supply, the top 25 companies accounts for approximately 42% of the retail market (U.S. Census Bureau and Home Channel News, 2002)®. This list was derived with the help of

lists compiled by the Chain Store Guide and was based on business classification and annual sales in 1998 for wholesalers and 2001 for retailers.

Data Collection

Data collection efforts began in the fall of 2002. On November 11th the first questionnaire was sent, with a cover letter explaining the purpose of the study and other instructions including descriptions of the two incentives to respond (entry into a prize drawing and a summary of the findings of the study). A reminder postcard was mailed November 19th. A second questionnaire was mailed on December 2nd, with a cover letter requesting participation from non-respondents. After these efforts 32 completed questionnaires were received. The original population of 200 was reduced by two undeliverable surveys and one survey that were not applicable, resulting in an adjusted population of 197 retailers, and an **adjusted response rate of 20.8 percent**.

Response Rates

The overall response rate was 20.8 percent. There was one survey that was not applicable and two undeliverable surveys. There were 41 responses from the adjusted population of 197.

Study Bias

This study may have bias because of the small sample sizes along with the low response rates. Also, it is biased more to the large end of the retail community. This exploratory research provides useful findings for launching and marketing a successful new product.

DEMOGRAPHIC DATA

Respondent Profile

LNO – Age

Respondents were evenly distributed among specified age groups. Of the thirty-six respondents who supplied age information, thirty-nine percent (n=14/36) fell into the 43-52 years age bracket, thirty-three percent (n=12/36) were age 53 and over, and the remaining twenty-eight percent (n=10/36) were 33 to 42 years old. See Figure 8.

LNO – Education

Of the respondents who completed the question regarding education level (n = 35), fifty-four percent completed graduate or professional training beyond college, and forty percent of respondents completed a college degree. See Figure 9.

LNO – Job Title

Respondents held various job positions within their organizations. Thirty-two percent (12/37) of respondents were Architects and twenty-seven percent (10/37 = 27%) were Engineers. The remaining job titles were Facility Maintenance Supervisors (6/37 = 16%), Construction Managers (6/37 = 16%), and Branch Heads (3/37 = 8%). See Figure 10.

Prime Contractors – Age

Respondents were evenly distributed among specified age groups. Of the respondents who supplied age information, forty-three percent (n=6/14) fell into the 43-52 years age bracket, and another twenty-nine percent (n=4/14) were age 53 and over. The remaining twenty-eight percent were evenly split between 23-32 years old, and 33 to 42 years old. See Figure 11.

Prime Contractors – Education

Of the respondents who completed the question regarding education level (n = 14), forty-three percent completed a college degree, and an additional twenty-one percent completed graduate degrees. See Figure 12.

Prime Contractors – Years with Company

Respondents were with their respective companies for an average of 15.46 years, with a minimum employment of 6 months to a maximum of 41 years.

Years with Company, per respondent: 1, 3, 4, 5, 6, 7, 8, 10, 18, 20, 23, 30, 41, 41

Table 24 – Years With Company (Prime Contractors)

"Top 200+" Builders – Age

Forty-seven percent of the respondents (n = 10/21) were in the age bracket 43 – 52. The age group 33 – 42 contained the second highest percent of respondents with twenty-nine percent (n = 6/21). The remaining twenty-four percent was split between the age brackets 53 and over and 23 – 32 with nineteen percent (n = 4/21) and five percent (n = 1/21) respectively. See Figure 13.

"Top 200+" Builders – Education

Fifty-seven percent of respondents (n = 12/21) completed a college degree. In addition, nineteen percent (n = 4/21) received training beyond college. The remaining twenty-four percent (n = 5/21) had some college or post high school training. See Figure 14.

"Top 200+" Builders – Job Title

Respondents were asked to indicate their job title with their companies. Their responses are summarized in the following table.

Job Title	Frequency
Construction Manager	2
President	2
Purchasing Manager	2
Architect	1
CEO	1
Director of New Home Construction	1
Director of Supply Chain Mgmt.	1
North American Purchasing Mgr.	1
President Production	1
President/Owner	1
Project Manager	1
Purchaser	1
Senior Director of Special Projects and New Products	1
VP of Operations	1
VP of Procurement	1
VP, Director of Homebuilding Systems and Operations	1
VP/Gen. Mgr./Co-Owner	1
VP/GM	1

Table 25 – Job Title of "Top 200+" Respondents

"Top 200+" Builders – Years with Company

Respondents had worked for their companies for and average of 8.14 years with a minimum of one year and a maximum of thirty years.

	Years with Company												
	1	2	3	4	5	6	8	9	10	11	14	21	30
Count	3	1	1	2	2	1	2	3	2	1	1	1	1

Table 26 – Years with Company ("Top 200+")

Wholesalers – Age

Fifty-nine percent of the respondents (n = 17/29) were in the age bracket 43 – 52. The age group 53 and Over contained the second highest percent of respondents with twenty-four percent (n = 7/29). The remaining seventeen percent (n = 5/29) were in the age bracket 33 - 42. See Figure 15.

Wholesalers – Education

Fifty-nine percent of respondents (n = 17/29) completed a college degree. In addition, thirty-four percent (n = 10/29) received some college or post high school training. The remaining seven percent (n = 2/29) completed high school or equivalent. See Figure 16.

Wholesalers – Job Title

Respondents were asked to indicate their job title with their companies. Their responses are summarized in the following table.

Job Title	Count
General Manager	3
President	2
Sales Manager	2
Building Project Manager	1
Corporate Buyer	1
Corporate Purchasing	1
Department Manager	1
Director of Commodity Lumber	1
Director of Purchasing	1
Director of Purchasing and Transportation	1
Division Manager	1
Industrial Sales	1
Lumber and Building Materials Manager	1
Lumber Trader (Buy and Sell)	1
Marketing Manager	1
Operation Manager, Buyer	1
Purchasing Agent	1
Vice-President	1
Vice-President of Sales	1
Vice-President Operations	1
Vice-President Operations/Purchasing	1
Vice-President Product Management	1
Vice-President Purchasing and Distribution Systems	1
Vice-President Sales and marketing	1
Total	32

Table 27 – Job Title of Distributor Respondents

Wholesalers – Years with Company

Respondents had worked for their companies for and average of 17.52 years with a minimum of two years and a maximum of thirty-six years.

Years	Frequency	Percent
2	1	3.45
5	1	3.45
6	2	6.90
7	2	6.90
8	1	3.45
9	1	3.45
11	1	3.45
15	2	6.90
16	2	6.90
17	1	3.45
18	2	6.90
19	2	6.90
20	1	3.45
23	1	3.45
24	1	3.45
25	1	3.45
26	3	10.34
27	1	3.45
30	1	3.45
31	1	3.45
36	1	3.45
Total	29	100.00

Table 28 – Years with Company (Wholesalers)

Retailers – Age

Fifty-seven percent of the respondents (n = 23/40) were in the age bracket 43 – 52. The age group 33 – 42 contained the second highest percent of respondents with twenty-two percent (n = 9/40). The remaining twenty-one percent was split between the age brackets 53 and over and 23 – 32 with eighteen percent (n = 7/40) and three percent (n = 1/40) respectively. See Figure 17.

Retailers – Education

Forty-four percent (n = 18/40) of respondents had some college or post high school training. Thirty-three percent of respondents (n = 13/40) completed a college degree. In addition, five percent (n = 2/40) received training beyond college. Thirteen percent (n = 6/40) completed high school or equivalent while three percent (n = 1/40) did not complete high school. See Figure 18.

Retailers – Job Title

Respondents were asked to indicate their job title with their companies. Their responses are summarized in the following table.

Job Title	Count
Purchasing Manager	5
Buyer	4
Purchasing Agent	3
Director of Purchasing	2
Purchasing Director	2
Buyer home remodeling	1
Buyer, Regional Manager	1
Forest Products Buyer	1
General Buyer/Sales	1
General Manager	1
Inventory Manager - Commodity Buyer	1
Location Manager	1
Lumber Buyer	1
Manager	1
Marketing Manager	1
Operation Manager	1
Owner	1
Purchase Director	1
Purchasing	1
Purchasing and Planning Manager	1
Purchasing Consultant	1
Sales Manager	1
Secretary/Treasurer - Owner	1
Senior Buyer	1
Senior Merchandise Manager	1
Senior Vice-President Purchasing and Marketing	1
Vice-President - Purchasing, Merchandising, Advertising	1
Total	41

Table 29 – Job Title of Retailer Respondents

Retailers – Years with Company

Respondents had worked for their companies for and average of 15.33 years with a minimum of two years and a maximum of thirty-three years.

Years	Frequency	Percent
2	1	2.50
3	2	5.00
4	2	5.00
5	3	7.50
6	3	7.50
7	4	10.00
8	1	2.50
9	1	2.50
10	3	7.50
16	1	2.50
18	2	5.00
20	1	2.50
21	1	2.50
22	1	2.50
23	6	15.00
26	1	2.50
28	1	2.50
29	2	5.00
30	2	5.00
31	1	2.50
33	1	2.50
Total	40	100.00

Table 30 – Years with Company (Retailers)

Company/Facility Profile

LNO – Repair and Construction Dollar Value

Twenty-four respondents provided information about the dollar value of all repair/maintenance and new construction at facilities under their jurisdiction. The average amount per facility spent on repair and maintenance was $206,395,161. The average expenditures on building construction per facility was $76,479,167.

Dollar value of repair/maintenance and construction is summarized below. See also Figure 19 and Figure 20.

	N	Total	Mean
Repair/Maintenance	21	$4,334,298,379	$206,395,161
Construction	24	$1,835,500,000	$76,479,167

Table 31 – Building Dollars Spent at Facilities, 2001

	Repair/Maintenance	Construction
$500,000.00	1	
$1,000,000.00	1	
$1,100,000.00		1
$5,000,000.00	2	
$5,198,379.00		1
$7,000,000.00	1	1
$10,000,000.00	4	2
$12,000,000.00	1	
$16,000,000.00	1	
$20,000,000.00	1	
$25,000,000.00		1
$30,000,000.00	1	1
$35,000,000.00	1	
$38,000,000.00	1	
$40,000,000.00		1
$50,000,000.00	1	3
$51,000,000.00	1	1
$60,000,000.00		2
$80,000,000.00	3	
$85,000,000.00	1	
$100,000,000.00		1
$150,000,000.00	1	
$165,000,000.00		1
$300,000,000.00		1
$400,000,000.00	1	
$650,000,000.00	1	
$760,000,000.00		2
$800,000,000.00		1
$1,000,000,000.00		1
TOTAL (N)	24	21

Table 32 – Detail of Expenditures

LNO – Number of Personnel Under Jurisdiction

Twenty-five respondents (25/37 = 68%) provided information regarding the number of personnel under their jurisdiction. Respondents were asked to estimate personnel at their facilities as Maintenance and Repair of Facilities, Construction Administration, and Specifying and Selecting Construction Materials. See Figure 21.

n=25	Total	Mean
Maintenance/repair facilities	3685	147
Construction administration	3092	124
Specify and select materials	1128	45
TOTAL	**7905**	**105**

Table 33 – Personnel Summary

	Maintain/repair facilities	Construction administration	Specify/select materials
1	0	0	35
2	0	32	0
3	0	7	0
4	0	500	0
5	0	1200	0
6	0	50	0
7	0	200	30
8	4	0	0
9	4	4	4
10	10	5	6
11	11	12	9
12	20	15	20
13	30	0	0
14	30	140	20
15	30	22	30
16	51	0	0
17	60	40	10
18	60	60	130
19	75	150	75
20	100	15	20
21	200	20	20
22	250	30	15
23	250	25	4
24	1000	300	300
25	1500	265	400
Total N	*25*	*25*	*25*
Mean	**147**	**124**	**45**
Range	**1500**	**1200**	**400**

Table 34 – Personnel Count Detail

Prime Contractors – Sales

Sixty-four percent of respondents (9/14 = 64%) work for companies with total 2001 sales of over $25,000,000. The remaining thirty-six percent of respondents work for companies with 2001 total sales of $20,000,001 to $25,000,000. See Figure 22.

Prime Contractors – Years in Non-Residential Construction Industry

Respondents were asked to indicate how many years their company had been involved in the nonresidential construction industry.

	Years
Mean	52.07
Range	126
Minimum	0
Maximum	126
Sum	729

Table 35 – Summary of Years in Nonresidential Construction Industry

Years in nonresidential construction industry	Frequency	Percent
0	1	7.1
20	4	28.6
26	1	7.1
30	1	7.1
31	1	7.1
60	1	7.1
82	2	14.3
100	1	7.1
112	1	7.1
126	1	7.1
Total = 679 years	**14**	**100.0**

Table 36 – Detail of Years in Nonresidential Construction Industry

Prime Contractors – Structures Completed

Respondents were asked how many nonresidential and residential structures their company completed in 2001.

	Number Structures
Mean	77.79
Range	350
Minimum	0
Maximum	350
Sum	1089

Table 37 – Count of Residential Structures Built, 2001

Number of Residential Structures	Frequency	Percent
0	5	35.7
3	1	7.1
5	1	7.1
6	1	7.1
25	1	7.1
40	1	7.1
160	1	7.1
200	1	7.1
300	1	7.1
350	1	7.1
Total = 1089	**14**	**100.0**

Table 38 – Count per Respondent of Residential Structures Built, 2001

	Number Structures
Mean	42.14
Range	200
Minimum	0
Maximum	200
Sum	590

Table 39 – Count of Nonresidential Structures Built, 2001

Number of Nonresidential Structures	Frequency	Percent
0	3	21.4
5	1	7.1
7	1	7.1
15	2	14.3
20	1	7.1
35	1	7.1
50	1	7.1
75	2	14.3
93	1	7.1
200	1	7.1
Total = 590	**14**	**100.0**

Table 40 – Count per Respondent of Nonresidential Structures Built, 2001

Prime Contractors – Sales Revenue Source

The majority of respondents, ninety-two percent (n = 12/13) build primarily nonresidential structures. Sixty-two percent (n = 8/13) of respondents do some business in the residential construction industry. However, of those respondents, only 1 respondent does more than thirty percent of their business in residential construction.

Case	Residential revenue %	Nonresidential revenue %	Maintenance & repair %	Other % (Industrial)	Other % (Unspecified)
1	2	96	2	.	.
2	10	80	10	.	.
3	0	95	5	.	.
4	0	60	40	.	.
5	0	0	0	100	.
6	80	0	20	.	.
7	0	100	0	.	.
8	15	85	0	.	.
9	1	99	0	.	.
10	0	100	0	.	.
11	10	90	0	.	.
12	30	70	0	.	.
13	1	15	10	.	74

Table 41 – Sales Revenue Detail by Construction Type

Prime Contractors – Number of States Operated in and Top Revenue State

Respondents were asked whether their company did business in multiple states. Eighty percent of the companies responding do business in more than one state. The respondents' companies, on average, do business in 7.21 states. Respondents were only asked to list the state where their company generated the greatest amount of revenue.

Number of States in which Company Does Business	Most Revenue
1	IL
1	HI
3	HI
3	MD
4	VA
6	CA
7	TX
8	CA
10	TX
10	CA
10	MD
10	FL
12	VA
16	VA

Table 42 – States in which Companies Generate Greatest Revenue

"Top 200+" Builders – Sales Revenue Source

Respondents were asked to rank their sources of revenue between different categories. All of the respondents generated the majority of their revenue through the building of residential structures with the average amount of revenue generated being 97.39 percent. Six respondents indicated that they produce some revenue from nonresidential structures averaging 4.17 percent of their revenue produced. Two respondents indicated other sources of revenue. One did not specify the activity and produced 5 percent of their revenue, and the other produced 30 percent of their revenue through land development.

Case	Residential revenue %	Nonresidential revenue %	Maintenance & repair %	Other % (Industrial)	Other % (Land Development)	Other % (Unspecified)
1	98	2	0			
2	95	0	0			5
3	90	10	0			
4	90	10	0			
5	70	0	0		30	
6	99	1	0			
7	99	1	0			
8	99	1	0			
9	100	0	0			
10	100	0	0			
11	100	0	0			
12	100	0	0			
13	100	0	0			
14	100	0	0			
15	100	0	0			
16	100	0	0			
17	100	0	0			
18	100	0	0			
19	100	0	0			
20	100	0	0			
21	100	0	0			
22	100	0	0			
23	100	0	0			

Table 43 – Sources of Revenue

"Top 200+" Builders – Number of States Operated in and Top Revenue State

Respondents were asked if their company conducted business in multiple states. Their companies operate in an average of 7.91 states with sixty-eight percent operating in more than one state. The maximum number of states operated in was forty-eight. The breakdown in number of states operated in can be seen in the following table.

Number of States									
1	2	3	4	5	13	19	22	30	48
7	2	3	3	2	1	1	1	1	1

Table 44 – Number of States

In addition respondents were asked to indicate what state they produced the most revenue in. This can be seen in the following table:

State	Count
Unspecified	1
CA	2
FL	3
GA	3
IN	1
MD	1
MI	2
MO	1
NV	1
OH	2
PA	2
TN	1
TX	2
WI	1

Table 45 – State Producing Greatest Revenue

Wholesalers – Sales Revenue Source

Respondents were asked to indicate what percentage of their company's sales revenue was generated from different activities. They generated on average 86.74% of their revenue from building material sales.

Case	Building Material %	Home Decor/Floor Coverings %	Hardware %	Lawn and garden %	Paint %	Other %	Other - Name
1	75%	.	.	.	.	25%	Farm and Ranch
2	100%	.	.	.	.	.	
3	80%	15%	50%	.	.	.	
4	98%	.	1%	1%	.	.	
5	100%	.	.	.	.	.	
6	100%	.	.	.	.	.	
7	20%	30%	.	.	.	50%	Plumbing
8	100%	.	.	.	.	.	
9	90%	.	10%	.	.	.	
10	30%	1%	.	1%	.	68%	Int/ext doors and parts, hardwood lumber, plywood, melanens, MDF, Industrial grade particle board
11	100%	.	.	.	.	.	
12	98%	.	2%	.	.	.	
13	95%	5%	.	.	.	.	
14	100%	.	.	.	.	.	
15	60%	10%	10%	10%	10%	.	
16	55%	10%	15%	.	.	20%	Roofing
17	100%	.	.	.	.	.	
18	100%	.	.	.	.	.	
19	100%	.	.	.	.	.	
20	50%	30%	10%	5%	5%	.	
21	93%	5%	.	2%	.	.	
22	100%	.	.	.	.	.	
23	100%	.	.	.	.	.	
24	.	18%	.	.	8%	74%	Windows and Doors
25	100%	.	.	.	.	.	
26	100%	.	.	.	.	.	
27	98%	.	2%	.	.	.	
28	100%	.	.	.	.	.	

Table 46 – Sales Revenue Sources per Respondent

	Distributor		
Activity	N	Mean	Std. Deviation
Building Material	27	83.3%	0.23
Home Decor/Floor Coverings	9	4.1%	0.11
Hardware	8	3.4%	0.16
Lawn and garden	5	0.6%	0.04
Paint	3	0.7%	0.03
Other	5	8.2%	0.24

Table 47 – Summary of Sales Revenue Sources

Wholesalers – Purchase Source

Respondents were asked to indicate the percentage of their company's purchases that were made from different sources. One company made all of their purchases from a buying co-op while the most frequently used source was direct from manufacturers with a mean of 90.11% of purchases.

Case	Manufacturer - Direct %	Stocking wholesaler/ distributor %	Non-Stocking wholesaler/ distributor %	Buying group/ co-op %	Other %	Other - Name
1	99%	1%	.	.	.	
2	90%	10%	.	.	.	
3	80%	20%	.	.	.	
4	95%	5%	.	.	.	
5	60%	40%	.	.	.	
6	95%	.	5%	.	.	
7	95%	.	.	.	5%	Import Broker
8	100%	.	.	.	.	
9	100%	.	.	.	.	
10	90%	10%	.	.	.	
11	80%	20%	.	.	.	
12	10%	90%	.	.	.	
13	100%	.	.	.	.	
14	95%	5%	.	.	.	
15	.	.	.	100%	.	
16	100%	.	.	.	.	
17	97%	3%	.	.	.	
18	100%	.	.	.	.	
19	100%	.	.	.	.	
20	80%	15%	5%	.	.	
21	100%	.	.	.	.	
22	97%	3%	.	.	.	
23	100%	.	.	.	.	
24	100%	.	.	.	.	
25	75%	5%	20%	.	.	
26	100%	.	.	.	.	
27	100%	.	.	.	.	
28	95%	.	5%	.	.	

Table 48 – Purchase Sources per Respondent

	Distributor		
Source	N	Mean	Std. Deviation
Manufacturer - Direct	27	86.9%	0.19
Stocking wholesaler/distributor	13	8.1%	0.24
Non-Stocking wholesaler/distributor	4	0.6%	0.08
Buying group/co-op	1	3.5%	.
Other	1	0.1%	.

Table 49 – Summary of Purchase Sources

Wholesalers – Customer Types

Respondents were asked to indicate the percent of their company’s sales made to different customer types. The most sales on average were made to Retailer – DIY focus (mean = 70.44%) with the smallest average sales being the Homeowner/End User with a mean of 10.88%).

Case	Homeowner/end user %	Builder/contractor - new construction %	Builder/ contractor - remodel %	Retailer - DIY focus %	Wholesaler/distributor %	Other %	Other - Name
1	.	.	.	95%	5%	.	
2	10%	55%	25%	.	10%	.	
3	.	.	.	80%	20%	.	
4	.	.	.	90%	10%	.	
5	5%	60%	35%	.	.	.	
6	.	.	.	30%	.	70%	Lumber Yard
7	.	.	.	.	.	100%	Manufactured Housing, Modular Housing, Recreational Vehicle
8	.	.	.	99%	1%	.	
9	.	.	.	100%	.	.	
10	.	.	.	95%	5%	.	
11	8%	57%	27%	.	.	8%	Commercial
12	2%	93%	5%	.	.	.	
13	.	50%	10%	40%	.	.	
14	.	.	.	60%	20%	20%	Manufactured Housing
15	10%	60%	20%	5%	5%	.	
16	.	10%	4%	86%	.	.	
17	1%	96%	3%	.	.	.	
18	.	.	.	90%	10%	.	
19	.	5%	.	.	95%	.	
20	50%	30%	20%	.	.	.	
21	.	75%	25%	.	.	.	
22	1%	15%	64%	18%	2%	.	
23	.	.	.	.	100%	.	
24	.	.	.	80%	.	20%	Commercial contractor
25	.	.	.	50%	.	50%	Furniture/ Fixture/ Cabinet manufacturers
26	.	10%	.	90%	.	.	
27	.	.	.	100%	.	.	
28	.	.	.	60%	.	40%	Treate???/

Table 50 – Customer Types per Respondent

	Distributor		
Custormer	N	Mean	Std. Deviation
Homeowner/end user	8	3.1%	0.16
Builder/contractor - new construction	13	21.9%	0.31
Builder/contractor - remodel	11	8.5%	0.18
Retailer - DIY focus	18	45.3%	0.30
Wholesaler/distributor	12	10.1%	0.35
Other	7	11.0%	0.32

Table 51 – Summary of Customer Types

Wholesalers – Number of States Operated in and Top Revenue State

Respondents were asked if their company conducted business in multiple states. Their companies operate in an average of 13.75 states with ninety-six percent operating in more than one state. The maximum number of states operated in was fifty. The breakdown in number of states operated in can be seen in the following table.

# of States	Count
1	1
2	4
3	1
4	2
5	1
6	2
7	3
9	2
10	2
12	1
13	1
14	1
15	2
30	1
45	1
47	1
48	1
50	1

Table 52 – Number of States

In addition respondents were asked to indicate what state they produced the most revenue in. This can be seen in the following table:

State	Count
IN	3
MO	2
NC	2
ND	2
NJ	2
TX	2
WI	2
CA	1
CO	1
CT	1
HI	1
IA	1
KY	1
MA	1
NY	1
OH	1
OR	1
TN	1
VA	1

Table 53 – State Producing Greatest Revenue

Retailers – Sales Revenue Source

Respondents were asked to indicate what percentage of their company's sales revenue was generated from different activities. They generated on average 77.15% of their revenue from building material sales.

Case	Building Material %	Home Decor/Floor Coverings %	Hardware %	Lawn and garden %	Paint %	Other %	Other - Name
1	80%	.	.	.	.	20%	Millwork
2	27%	2%	5%	11%	5%	50%	Kitchen sales
3	85%	10%	5%	.	.	.	
4	40%	10%	12%	3%	10%	25%	Kitchen and Bathroom Millwork
5	80%	.	15%	.	5%	.	
6	65%	15%	10%	2%	1%	7%	
7	90%	5%	5%	.	.	.	
8	85%	5%	5%	.	5%	.	
9	99%	.	1%	.	.	.	
10	90%	.	4%	3%	3%	.	
11	98%	.	1%	.	1%	.	
12	98%	.	2%	.	.	.	
13	80%	.	4%	.	.	16%	millwork
14	93%	.	2%	4%	1%	.	
15	98%	.	1%	.	1%	.	
16	85%	3%	8%	2%	2%	.	
17	97%	.	3%	.	.	.	
18	5%	5%	15%	15%	5%	55%	General Merchandise
19	80%	.	15%	5%	.	.	
20	90%	7%	3%	.	.	.	
21	80%	.	10%	2%	8%	.	
22	75%	.	.	.	.	25%	Installed Sales
23	60%	10%	12%	1%	2%	15%	millwork
24	57%	18%	12%	1%	3%	.	
25	95%	.	5%	.	.	.	
26	100%	.	.	.	.	.	
27	90%	5%	5%	.	.	.	
28	60%	.	2%	2%	11%	25%	Livestock Equipment
29	86%	.	10%	1%	3%	.	
30	50%	5%	15%	.	20%	10%	
31	98%	.	2%	.	.	.	
32	85%	5%	5%	1%	1%	3%	Concrete product
33	75%	.	20%	.	5%	.	
34	23%	16%	15%	21%	9%	16%	Plumbing/Electric
35	100%	.	.	.	.	.	
36	28%	1%	2%	2%	2%	65%	Lumber, Millwork, Tools, Electricity, Plumbing
37	90%	1%	3%	.	2%	4%	
38	85%	10%	5%	.	.	.	
39	85%	.	10%	.	.	5%	
40	99%	.	.	.	1%	.	

Table 54 – Sales Revenue Sources per Respondent

Activity	N	Mean	Std. Deviation
Building Material	40	77.15%	0.24
Home Decor/Floor Coverings	18	3.3%	0.05
Hardware	35	6.2%	0.05
Lawn and garden	16	1.9%	0.06
Paint	23	2.6%	0.05
Other	15	8.5%	0.19

Table 55 – Summary of Sales Revenue Sources

Retailers – Purchase Source

Respondents were asked to indicate the percentage of their company's purchases that were made from different sources. On average 37.84% of purchases are made from a buying co-op while 37.59% are made from the Manufacture direct.

Case	Manufacturer - Direct %	Stocking wholesaler/ distributor %	Non-Stocking wholesaler/ distributor %	Buying group/ co-op %	Other %	Other - Name
1	20%	40%	.	40%	.	
2	30%	20%	20%	30%	.	
3	15%	15%	.	70%	.	
4	25%	10%	5%	60%	.	
5	.	5%	.	95%	.	
6	50%	5%	20%	20%	5%	Unspecified
7	20%	30%	10%	40%	.	
8	25%	30%	20%	25%	.	
9	10%	15%	.	75%	.	
10	10%	20%	.	70%	.	
11	30%	30%	.	40%	.	
12	75%	25%	.	.	.	
13	85%	15%	.	.	.	
14	10%	60%	10%	20%	.	
15	3%	90%	.	7%	.	
16	98%	1%	1%	.	.	
17	60%	30%	9%	1%	.	
18	60%	40%	.	.	.	
19	80%	20%	.	.	.	
20	60%	40%	.	.	.	
21	30%	30%	.	40%	.	
22	60%	30%	10%	.	.	
23	10%	40%	.	50%	.	
24	40%	30%	20%	5%	.	
25	45%	45%	5%	5%	.	
26	50%	40%	.	10%	.	
27	70%	25%	5%	.	.	
28	25%	75%	.	.	.	
29	30%	10%	10%	50%	.	
30	40%	10%	.	50%	.	
31	40%	10%	10%	40%	.	
32	15%	25%	50%	15%	.	
33	35%	50%	10%	5%	.	
34	50%	30%	.	20%	.	
35	40%	35%	5%	20%	.	
36	10%	35%	.	55%	.	
37	.	30%	20%	50%	.	
38	20%	5%	5%	70%	.	
39	15%	50%	.	35%	.	
40	.	40%	.	60%	.	

Table 56 – Purchase Sources per Respondent

	Retailer		
Source	N	Mean	Std. Deviation
Manufacturer - Direct	37	34.8%	0.24
Stocking wholesaler/distributor	40	29.7%	0.19
Non-Stocking wholesaler/distributor	19	6.1%	0.11
Buying group/co-op	31	29.3%	0.24
Other	1	0.1%	.

Table 57 – Summary of Purchase Sources

Retailers – Customer Types

Respondents were asked to indicate the percent of their company's sales made to different customer types. The most sales on average were made to Builder/Contractor – new construction (mean = 65.43%).

Case	Homeowner/end user %	Builder/contractor - new construction %	Builder/ contractor - remodel %	DIY'er %	Wholesaler/distributor %	Other %	Other - Name
1	5%	80%	15%	.	.	.	
2	30%	20%	20%	30%	.	.	
3	10%	65%	10%	15%	.	.	
4	20%	40%	25%	15%	.	.	
5	10%	70%	20%	.	.	.	
6	5%	85%	5%	.	.	5%	
7	.	90%	10%	.	.	.	
8	5%	80%	5%	10%	.	.	
9	.	95%	5%	.	.	.	
10	15%	70%	15%	.	.	.	
11	5%	90%	5%	.	.	.	
12	3%	76%	10%	1%	.	10%	Commercial
13	2%	95%	3%	.	.	.	
14	5%	40%	40%	4%	1%	.	
15	5%	80%	10%	5%	.	.	
16	5%	85%	3%	2%	5%	.	
17	10%	75%	13%	.	2%	.	
18	5%	1%	4%	90%	.	.	
19	30%	70%	.	.	.	.	
20	3%	80%	15%	2%	.	.	
21	10%	70%	20%	.	.	.	
22	10%	80%	10%	.	.	.	
23	25%	55%	10%	10%	.	.	
24	10%	40%	40%	10%	.	.	
25	5%	85%	5%	5%	.	.	
26	5%	80%	15%	.	.	.	
27	10%	60%	30%	.	.	.	
28	50%	40%	10%	.	.	.	
29	15%	35%	35%	15%	.	.	
30	20%	30%	30%	20%	.	.	
31	.	100%	.	.	.	.	
32	15%	75%	4%	5%	1%	.	
33	20%	20%	20%	.	.	40%	manufacturer
34	70%	5%	10%	15%	.	.	
35	2%	95%	3%	.	.	.	
36	20%	30%	30%	10%	5%	5%	Misc.
37	10%	80%	10%	.	.	.	
38	5%	90%	.	5%	.	.	
39	10%	80%	10%	.	.	.	
40	10%	80%	10%	.	.	.	

Table 58 – Customer Types per Respondent

	Retailer		
Custormer	N	Mean	Std. Deviation
Homeowner/end user	37	12.4%	0.14
Builder/contractor - new construction	40	65.4%	0.26
Builder/contractor - remodel	37	13.4%	0.10
DIY'er	19	6.7%	0.20
Wholesaler/distributor	5	0.4%	0.02
Other	4	1.5%	0.17

Table 59 – Summary of Customer Types

Retailers – Number of States Operated in and Top Revenue State

Respondents were asked if their company conducted business in multiple states. Their companies operate in an average of 2.89 states with thirty-seven percent operating in only one state. The maximum number of states operated in was twenty. The breakdown in number of states operated in can be seen in the following table.

# of States	Count
1	14
2	9
3	6
4	4
5	1
6	2
7	1
20	1

Table 60 – Number of States

In addition respondents were asked to indicate what state they produced the most revenue in. This can be seen in the following table:

State	Count
CA	3
MA	3
MI	3
MN	3
TX	3
AR	2
FL	2
NC	2
NH	2
NJ	2
OH	2
PA	2
GA	1
IA	1
IL	1
NE	1
NY	1
OR	1
RI	1
TN	1

Table 61 – State Producing Greatest Revenue

PRODUCT USE

Knowledge, Experience, and Use of WPC's

All five populations were asked to rate their knowledge of and experience with woodfiber-plastic composites on a 5-point Likert scale (0 = no knowledge to 5 = much knowledge). Respondents rated both their **knowledge** of (mean = 2.92) and **experience** (mean = 2.50) with WPC's as below average. In addition, the LnO population was asked to indicate whether woodfiber-plastic composites were ever used at their facility and if so what building applications they were used in.

Knowledge – LNO's, Prime Contractors, "Top 200+" Builders, Wholesalers, & Retailers

Respondents from all five populations were asked to rate their knowledge of woodfiber-plastic composites used in building applications. The total mean, 2.92, was slightly below average. The respondents from the Retailers population felt they had the most knowledge of WPC's, mean = 3.68.

	0 - No Knowledge	1	2	3	4	5 - Much Knowledge	N	Mean	Std. Deviation
Total	5	18	22	48	30	16	139	2.92	1.30
LnO		11	11	10	3		35	2.14	0.97
Prime	2	1	4	6		1	14	2.29	1.33
"Top 200+"	1	2	3	8	4	3	21	3.00	1.34
Wholesalers	2	4	2	8	8	5	29	3.07	1.51
Retailers			2	16	15	7	40	3.68	0.83

Table 62 – Knowledge of Woodfiber-Plastic Composites

Experience – LNO's, Prime Contractors, "Top 200+" Builders, Wholesalers, & Retailers

Respondents from all five populations were asked to rate their experience with woodfiber-plastic composites used in building applications. The total mean, 2.50, was below average. The respondents from the Retailers population rated their experience with WPC's highest, mean = 3.38.

	0 - No Experience	1	2	3	4	5 - Much Experience	N	Mean	Std. Deviation
Total	14	22	32	37	22	13	140	2.50	1.43
LnO	6	12	11	4	3		36	1.61	1.15
Prime	2	2	5	3	1	1	14	2.14	1.41
"Top 200+"	4	4	5	3	4	1	21	2.10	1.55
Wholesalers	2	4	4	9	6	4	29	2.86	1.46
Retailers			7	18	8	7	40	3.38	0.98

Table 63 – Experience with Woodfiber-Plastic Composites

Use – LNO's

Respondents of the LnO population were asked to indicate whether they had ever used woodfiber-plastic composites at their facility and if so to indicate what applications they were used in. Of the thirty-seven respondents, 48.6 percent (n = 18) have not used woodfiber-plastic composites at their facility. Twenty-four percent (n = 9) have used woodfiber-plastic composites, and the remaining 27 percent (n=10) were not aware of whether they had used woodfiber-plastic composites. See Figure 27.

Eleven responses from nine respondents are listed in Table 64. These responses specify applications of woodfiber-plastic composites by respondents. Dates are listed where they were provided.

Application	Date
Doors - FRP	
Toilet partition systems	March, 1992
Pier application for Fence Repair	October, 2001
Fender piles	October, 1998
Countertops, kitchen and bath	
Benches (n = 2)	September, 1997
Exterior furnishings	January, 1996
Composite Piles at wharf	
Decking, handicap ramps (n = 2)	January, 1995 November, 2002
Siding, family housing	November, 1998
New family housing	January, 1998

Table 64 – Woodfiber-Plastic Composite Building Applications

Current position in organization * Woodfiber-plastic composite use Crosstabulation

		Ever used woodfiber-plastic composites? YES	NO	DON'T KNOW	Total
Engineer	Count	1	2	7	10
	% Woodfiber-plastic use	11.1%	11.1%	70.0%	27.0%
Facility Maintenance Supervisor	Count	3	3		6
	% Woodfiber-plastic use	33.3%	16.7%		16.2%
Architect	Count	3	7	2	12
	% Woodfiber-plastic use	33.3%	38.9%	20.0%	32.4%
Construction Administration	Count	2	6	1	9
	% Woodfiber-plastic use	22.2%	33.3%	10.0%	24.3%
Total	Count	9	18	10	37
	% Woodfiber-plastic use	100.0%	100.0%	100.0%	100.0%

Table 65 – Woodfiber-Plastic Composite Use by Job Title[6]

Location * Woodfiber-plastic use Crosstabulation

		Ever Used Woodfiber-plastic Composites? YES	NO	DON'T KNOW	Total
Atlantic/Northeast	Count	3	2	3	8
	Woodfiber-plastic use	33.3%	11.1%	30.0%	21.6%
Pacific/Northwest	Count	2	2	2	6
	Woodfiber-plastic use	22.2%	11.1%	20.0%	16.2%
Southwest	Count	3	7	4	14
	Woodfiber-plastic use	33.3%	38.9%	40.0%	37.8%
South	Count	1	7	1	9
	Woodfiber-plastic use	11.1%	38.9%	10.0%	24.3%
Total	Count	9	18	10	37
	Woodfiber-plastic use	100.0%	100.0%	100.0%	100.0%

Table 66 – Woodfiber-Plastic Composite Use by Region[7]

6 Four primary job titles are represented in Table 30. The three Branch Head titles were merged with Construction Managers into one group, Construction Administration.

7 Four primary regions are represented in Table 31. The one respondent from the Northwest region was added to the Pacific region, and the one respondent from the Northeast region was added to the Atlantic region.

Product Use and Familiarity

Product Use Phrases – Prime Contractors & “Top 200+” Builders

Respondents from the Prime Contractors and “Top 200+” Builder populations were asked to describe their use of particular products as building components. As illustrated in the tables below Wood trusses are the most widely used product for the total (n=31) and the Prime Contractors (n=11). “Top 200+” used Beams/Headers, LVL the most (n=21). Respondents were least familiar with WPC Exterior Door Sills (n=9) followed by Precast Concrete Wall Panels (n=36).

Total						
Product	**N**	**1 Not familiar**	**2 familiar, never used**	**3 trial basis**	**4 using**	**5 used, but stopped**
Precast concrete wall panels	36	7	20	6	2	1
Preassembled wall sections	36	3	20	4	8	1
Beams/headers, LVL	35	1	3		30	1
I-joists, LVL	35	2	7	4	21	1
Wood trusses	36		4		31	1
Fiber cement siding	36	5	8	4	18	1
WPC decking	36	3	13	8	10	2
WPC railings for decking	36	4	15	9	6	2
WPC windows	36	6	26	1	3	
WPC exterior door sills	36	9	19	1	7	
Structural composite lumber	35	5	10	4	16	
Light-gauge steel framing	36	3	13	5	11	4

Table 67 – Product Familiarity and Use, Total

Prime Contractors						
Product	**N**	**1 Not familiar**	**2 familiar, never used**	**3 trial basis**	**4 using**	**5 used, but stopped**
Precast concrete wall panels	13	4	4	3	2	
Preassembled wall sections	13	1	6	3	3	
Beams/headers, LVL	13		3		9	1
I-joists, LVL	13	1	4	2	5	1
Wood trusses	13		2		11	
Fiber cement siding	13		4	2	7	
WPC decking	13	1	5	3	4	
WPC railings for decking	13	2	4	4	3	
WPC windows	13		10	1	2	
WPC exterior door sills	13	2	8	1	2	
Structural composite lumber	13	3	4	2	4	
Light-gauge steel framing	13			2	10	1

Table 68 – Product Familiarity and Use, Prime Contractors

"Top 200+"						
Product	N	1 Not familiar	2 familiar, never used	3 trial basis	4 using	5 used, but stopped
Precast concrete wall panels	23	3	16	3		1
Preassembled wall sections	23	2	14	1	5	1
Beams/headers, LVL	22	1			21	
I-joists, LVL	22	1	3	2	16	
Wood trusses	23		2		20	1
Fiber cement siding	23	5	4	2	11	1
WPC decking	23	2	8	5	6	2
WPC railings for decking	23	2	11	5	3	2
WPC windows	23	6	16		1	
WPC exterior door sills	23	7	11		5	
Structural composite lumber	22	2	6	2	12	
Light-gauge steel framing	23	3	13	3	1	3

Table 69 – Product Familiarity and Use, "Top 200+"

If the respondent answered, "Used, but stopped," they were asked to indicate the reason for no longer using the product. These reasons can be seen in the following table:

Building Component	Reason
Beams/headers, LVL	if specified, we use it
fiber cement siding	supply & warranty problems
fiber cement siding	too heavy
I-joists, LVL	if specified, we use it
light-gauge steel framing	metal noise (floor framing)
light-gauge steel framing	high labor cost, shows dark lines on stud dye to condensation
light-gauge steel framing	other trade problems
light-gauge steel framing	poor installation
light-gauge steel framing	not specified
WPC outdoor decking	not currently building decks
WPC outdoor decking	high cost
WPC railings for decking	high cost

Table 70 – Reason for No Longer Using Product

Product Familiarity Phrases – Wholesalers & Retailers

Respondents from the Wholesalers and Retailers populations were asked to describe their familiarity of particular products as building components. As illustrated in the tables below LVL I-joists are the most widely carried product for the total (n=49) followed by LVL Beams/Headers (n=48). Respondents were least familiar with WPC Windows (n=10) followed by WPC Exterior Door Sills (n=10).

Total						
Product	N	1 Not familiar	2 familiar, never carried	3 trial basis	4 carrying	5 carried, but stopped
Beams/headers, LVL	67	6	10	1	48	2
I-joists, LVL	67	6	10		49	2
Wood trusses	65	5	19	3	35	3
Fiber cement siding	66	3	16	3	42	2
WPC decking	65	4	8	3	47	3
WPC railings for decking	66	3	18	4	38	3
WPC windows	65	14	26	5	19	1
WPC exterior door sills	66	10	26	4	24	2
Structural composite lumber	67	7	23	2	33	2
Light-gauge steel framing	66	5	25	4	29	3

Table 71 – Product Familiarity, Total

Wholesalers						
Product	N	1 Not familiar	2 familiar, never carried	3 trial basis	4 carrying	5 carried, but stopped
Beams/headers, LVL	29	6	8		13	2
I-joists, LVL	29	6	8		13	2
Wood trusses	27	5	12	2	6	2
Fiber cement siding	28	3	8	2	13	2
WPC decking	27	4	4	1	15	3
WPC railings for decking	28	3	8	1	13	3
WPC windows	27	8	10		8	1
WPC exterior door sills	28	6	8	1	11	2
Structural composite lumber	29	6	14		7	2
Light-gauge steel framing	28	3	13	4	6	2

Table 72 – Product Familiarity, Wholesalers

Retailers						
Product	N	1 Not familiar	2 familiar, never carried	3 trial basis	4 carrying	5 carried, but stopped
Beams/headers, LVL	38		2	1	35	
I-joists, LVL	38		2		36	
Wood trusses	38		7	1	29	1
Fiber cement siding	38		8	1	29	
WPC decking	38		4	2	32	
WPC railings for decking	38		10	3	25	
WPC windows	38	6	16	5	11	
WPC exterior door sills	38	4	18	3	13	
Structural composite lumber	38	1	9	2	26	
Light-gauge steel framing	38	2	12		23	1

Table 73 – Product Familiarity, Retailers

Year of First Use – Prime Contractors, "Top 200+" Builders, Wholesalers, & Retailers

Respondents were asked to indicate the year that they first used a list of products. The responses for the Total, Prime Contractors, "Top 200+" Builders, Wholesalers, and Retailers can be seen in the following tables. Wood Trusses were the product with the fist use date, 1920. Respondents most recently started using WPC Railings for Decking, 1993.

Total													
Year	Precast concrete wall panels	Preassembled wall sections	Beams/ headers, LVL	I-joists, LVL	Wood trusses	Structural composite lumber	Fiber cement siding	WPC decking	WPC railings for decking	WPC windows	WPC exterior door sills	Light-gauge steel framing	Other WPC Product
1920					1								
1956					1								
1957					1					1			
1960					3								
1963					1								
1965					3								
1967												1	
1968					1								
1969					1								
1970	1				6							3	
1971	1												
1972		1			1	2						2	
1973					4								
1974					1								
1975					2								
1978												1	
1979					1	1							
1980		1	6	5	6	2		1				7	
1982					2								
1983				1	1	1							
1984					1		1						
1985		3	1		2	1	1			1		2	1
1986			2	1	1	1							
1987			3	2	1	2							
1988					1							2	
1989			1	1	3	2							
1990	2	1	18	15	4	8	7	4	2	5	2	5	2
1991	1		1	1	1	1		1				2	
1992			3	2				2		1		2	
1993			5	4	2	3	1	1	2	1			
1994		2	8	7	2	7	8	2	3	1		1	1
1995			11	11	4	6	5	8	2	1	3	6	
1996	1		5	7		2	5	6	6	3		2	1
1997	1		3	3		2	6	7	6	2	1		
1998			6	7	4	1	8	10	8	3	2	2	1
1999	3	2	4	4	2	3	10	8	8	3	7	5	
2000			1	2	2	2	5	7	10	2	5	4	
2001		1	2	2	3	3	7	5	7	2	4	4	1
2002					2		2	3	4	4	2	2	
Total	10	11	80	75	71	50	66	65	58	30	26	53	7

Table 74 – Year of First Use, Total

Prime Contractors												
Year	Precast concrete wall panels	Preassembled wall sections	Beams/ headers, LVL	I-joists, LVL	Wood trusses	Structural composite lumber	Fiber cement siding	WPC decking	WPC railings for decking	WPC windows	WPC exterior door sills	Light-gauge steel framing
1920					1							
1965					1							
1970	1											
1971	1											
1972						1						
1980		1			1			1				3
1982					1							
1983					1							
1985		2			2	1	1					1
1986			1									
1988					1							1
1989						1						
1990	2	1	3	3	1	1	3			1	1	2
1991				1	1			1				
1992												2
1993									1			
1994		1				1						
1995			2	2		1						1
1996	1		1	1					1			
1997			1				2	2	1			
1998			2			1		1	2	2	1	1
1999	1	1										
2000								1	1		1	
2001							2					1
2002								1	1			

Table 75 – Year of First Use, Prime Contractors

"Top 200+"												
Year	**Precast concrete wall panels**	**Preassembled wall sections**	**Beams/ headers, LVL**	**I-joists, LVL**	**Wood trusses**	**Structural composite lumber**	**Fiber cement siding**	**WPC decking**	**WPC railings for decking**	**WPC windows**	**WPC exterior door sills**	**Light-gauge steel framing**
1960					1							
1969					1							
1970					1							
1972		1										
1973					1							
1974					1							
1975					1							
1979					1	1						
1980			1		2							
1982					1							
1984					1		1					
1985		1										
1986					1							
1987						1						
1989					2							
1990			6	4	1	2						
1991	1											1
1992			1									
1993			2	1	1	1						
1994		1	2	1	2	1	2					1
1995			4	3	2	3	1					1
1996			4	4		2	2					1
1997	1			1		1	1		1			
1998			1	3			1	3	2			
1999	2	1		1			3	2	1		1	2
2000						1	1	2	1	1		
2001		1	1	1	1		1	3	3		1	1
2002							1	1			1	1

Table 76 – Year of First Use, "Top 200+"

Wholesalers											
Year	**Beams/ headers, LVL**	**I-joists, LVL**	**Wood trusses**	**Structural composite lumber**	**Fiber cement siding**	**WPC decking**	**WPC railings for decking**	**WPC windows**	**WPC exterior door sills**	**Light-gauge steel framing**	**Other WPC Product**
1965			1								
1967										1	
1968			1								
1970			1							1	
1972				1						1	
1980	1	1	1								
1985								1			
1986	1	1		1							
1988										1	
1989	1	1									
1990	2	2		2	1	1	2	2	1	1	1
1991				1							
1992						1		1			
1993						1	1				
1994	1	1		1	1		2	1			
1995	2	3		1	2	2		1		2	
1996					2	4	2	3		1	1
1997	1				1	2	1		1		
1998	1	1	2		2	2	1				1
1999	1	1			1	2	3	1	2	1	
2000	1	1	2			1	3				
2001	1	1	1	1	3					1	1
2002					1	1	2	2	1		
Total	13	13	9	8	14	17	17	12	5	10	4

Table 77 – Year of First Use, Wholesalers

Retailers											
Year	**Beams/ headers, LVL**	**I-joists, LVL**	**Wood trusses**	**Structural composite lumber**	**Fiber cement siding**	**WPC decking**	**WPC railings for decking**	**WPC windows**	**WPC exterior door sills**	**Light-gauge steel framing**	**Other WPC Product**
1956			1								
1957			1					1			
1960			2								
1963			1								
1965			1								
1970			4							2	
1972			1							1	
1973			3								
1975			1								
1978										1	
1980	4	4	2	2						4	
1983		1		1							
1985	1									1	1
1987	3	2	1	1							
1989			1	1							
1990	7	6	2	3	3	3		2		2	1
1991	1									1	
1992	2	2				1					
1993	3	3	1	2	1			1			
1994	5	5		4	5	2	1				1
1995	3	3	2	1	2	6	2		3	2	
1996		2			1	2	3				
1997	1	2		1	2	3	3	2			
1998	2	3	2		5	4	3	1	1	1	
1999	3	2	2	3	6	4	4	2	4	2	
2000		1		1	4	3	5	1	4	4	
2001			1	2	1	2	4	2	3	1	
2002			2				1	2		1	
Total	35	36	31	22	30	30	26	14	15	23	3

Table 78 – Year of First Use, Retailers

PSYCHOGRAPHIC DATA

Selection and Purchasing

All five populations were asked about the role they play in the selection and purchase of building materials. Respondents play a greater role in selection and specification of new building materials than in actual purchase of new building materials. A 5-point Likert scale (0 = no influence to 5 = much influence) was used for respondents to rate their influence in the selection and purchase of building materials. For **selection** of new building materials, the mean influence as self-rated by respondents was 3.87, above average. The mean for respondents' role in **purchase** of new building materials was also above average, 3.55. In addition, LnO's were asked about their role in the selection and purchase of replacement building materials and also who made most of the decisions concerning selection and purchase of building materials for their unit.

Role in Selection of New Building Materials – LNO's, Prime Contractors, "Top 200+" Builders, Wholesalers, & Retailers

Respondents from all five populations were asked to rate their influence in the selection of new building materials. The mean across all five populations was 3.87. Respondents from the Retailers population rated themselves as having the greatest influence over the selection of new building materials (mean = 4.60). The responses for total respondents along with each individual population can be seen in the table below.

	Role in Selection of New Building Materials						N	Mean	Std. Deviation
	0 - No Influence	1	2	3	4	5 - Much Influence			
Total	4	5	12	20	45	56	142	3.87	1.28
LnO	3	3	6	7	12	6	37	3.08	1.50
Prime	1	2	2	3	5	1	14	2.86	1.46
"Top 200+"				2	8	12	22	4.45	0.67
Wholesalers			4	7	6	12	29	3.90	1.11
Retailers				1	14	25	40	4.60	0.55

Table 79 – Role in Selection of New Building Materials

Role in Selection of Replacement Building Materials – LNO's

The LnO population was asked to rate their influence of selection of replacement building materials in addition to selection of new materials. They rated themselves as having a greater amount of an influence on selecting replacement materials, 3.14, as compared to 3.08 for new materials. The data for selection of replacement materials is summarized in the table below.

	Role in Selection of Replacement Building Materials						N	Mean	Std. Deviation
	0 - No Influence	1	2	3	4	5 - Much Influence			
LnO	2	3	6	7	11	6	35	3.14	1.44

Table 80 – Role in Selection of Replacement Building Materials

Who Makes Selection Decisions for Building Materials – LNO's

In addition the LnO population was asked who makes most selection decisions for building materials for their unit. Of the thirty-five respondents who provided information about who makes most decisions regarding selection of building materials in their units, eight respondents specified multiple job titles. All responses were included. See Figure 20.

Respondents themselves, twenty-six percent of the time (n = 10), make building material selection decisions. Of those respondents who make building material selection decisions, fifty percent are Architects, twenty percent are Engineers and another twenty percent are Facility Maintenance Supervisors. The remaining ten percent listed job title as Branch Head.

Respondent makes Selection Decisions	Percent
Architects	50%
Engineer	20%
Facility Maintenance Supervisor	20%
Branch Head	10%

Table 81 – Selection Decisions by Respondent

Selection decisions by job title are further delineated in the Figure 24. Categories of Self and Other were broken down by job titles specified by respondents and by respondent's specification of Other.

Engineers comprised the largest group, thirty-four percent (n = 14), of those mentioned who participate in most selection decisions for building materials. ROICC officers in charge of construction were mentioned twenty-one percent of the time (n = 9). Sixteen percent (n = 7) of selection decisions are made by architects. Remaining selection decisions are made by contractors and others as depicted in the Figure 24.

Role in Purchasing New Building Materials – LNO's, Prime Contractors, "Top 200+" Builders, Wholesalers, & Retailers

Respondents from all five populations were asked to rate their influence in the purchase of new building materials. The mean across all five populations was 3.55. Respondents from the Retailers population rated themselves as having the greatest influence over the purchase of new building materials (mean = 4.63). The responses for total respondents along with each individual population can be seen in the table below.

	Role in Purchase of New Building Materials						N	Mean	Std. Deviation
	0 - No Influence	1	2	3	4	5 - Much Influence			
Total	12	13	10	12	40	55	142	3.55	1.66
LnO	11	11	3	4	4	4	37	1.76	1.74
Prime	1		3	4	5	1	14	3.07	1.27
"Top 200+"		1	2	1	7	11	22	4.14	1.17
Wholesalers		1	2	2	11	13	29	4.14	1.06
Retailers				1	13	26	40	4.63	0.54

Table 82– Role in Purchase of New Building Materials

Role in Purchasing Replacement Building Materials – LNO's

The LnO population was asked to rate their influence of purchasing of replacement building materials in addition to purchasing of new materials. They rated themselves as having almost equal influence on purchasing replacement materials, 1.74, and 1.76 for new materials. The data for selection of replacement materials is summarized in the table below.

	Role in Purchase of Replacement Building Materials						N	Mean	Std. Deviation
	0 - No Influence	1	2	3	4	5 - Much Influence			
LnO	10	9	7	2	3	4	35	1.74	1.69

Table 83 – Role in Purchase of Replacement Building Materials

Who Makes Purchasing Decisions for Building Materials – LNO's

In addition the LnO population was asked who makes most selection decisions for building materials for their unit. Some respondents (n = 3) named multiple job titles when asked who makes most purchasing decisions for building materials in their units. All responses were included. See Figure 25.

Number of respondents completing question:	n = 36
Total number of responses:	n = 41
Number of respondents providing multiple responses:	n = 3

Table 84 – Purchasing Decisions Response Counts

Purchasing decisions by job title are further delineated in Figure 26. Categories of Self and Other were broken down by job titles specified by respondents and by respondent's specification of Other.

Contractors (n = 13) and ROICC officers in charge of construction (n = 13) were mentioned most often as those responsible for purchasing decisions. Engineering firms help make purchasing decisions in ten percent of cases (n = 4). Seven percent (n = 3) of purchasing decisions are made by respondents themselves, where respondent's job titles were Facility Maintenance Supervisors. Remaining purchasing decisions, twenty percent, are made by others as indicated in Figure 26.

Durability Perceptions

Top 3 Problems – LNO's, Prime Contractors, & "Top 200+" Builders

The table below displays the respondents' in all three populations insights regarding durability problems with the three most problematic building components at their installations.

Studies show that the major types of durability problems for building components are the result of damage from

- *Moisture (fungal decay, expansion, warping)*
- *Fungal decay*
- *Mold*
- *Poor retention of finish (paint, stain)*
- *Insect (mainly termites)*
- *Weathering (UV from sunlight, surface erosion)*
- *Mechanical stresses (other than wind or earthquake)*
- *Poor design*
- *Improper installation*
- *Fire*
- *Structural overload (wind, hurricanes, tornadoes, and earthquakes)*

TOTAL			
Building Component	**Durability Problem**	**Problem Count**	**Number of times Component Mentioned**
ABS - tubs and showers	crack	1	1
Beams	crack and twist	1	1
Bearing Wall	structural	1	1
Brick veneer	lack of maintenance, old age	1	1
Brick Chimney	improper flashing	1	2
	weight of structure	1	
Carpet, ceramic tile	improper installation	2	6
	quick to wear out	1	
	poor design	1	
	wear from use	2	
Composite Wood	moisture	1	2
	poor retention of finish	1	
Concrete or masonry, concrete foundation	steel corrosion	2	8
	shrinkage/expansion/settlement	2	
	weathering	1	
	improper installation	1	
	structural	1	
	cracking	1	

TOTAL			
Building Component	**Durability Problem**	**Problem Count**	**Number of times Component Mentioned**
Controls	lack of maintenance	1	1
Decks	moisture	1	
	weathering	1	2
Doors, exterior (wood or metal), masonite doors, exterior door jamb	moisture, weathering, rot	4	
	denting	1	
	rotting	1	
	warping	1	
	fungal decay	1	
	abuse - low resistance to rough use	1	9
Drywall, wallboard	Mold, mildew, fungal decay	4	
	does not withstand abuse from sailors/marines	2	
	improper installation	1	
	mechanical stresses	1	8
Elevators	mechanical breakdown/stresses	2	
	poor design, installation	1	3
Exposed Steel (steel studs)	Rusting, ltd life span	2	2
Exterior Wood Work	moisture	1	
	expansion	1	
	poor retention of finish	1	3
Exterior Sheathing	water/mold problem	1	1
Fiber reinforced stucco (EIFS)	improper installation	2	
	weathering	1	
	poor design	1	4
Finger-joint Wood Trim	too noticeable	1	
	de-lam	1	2
Finish coatings (paint)	application, maintenance (poor life cycle)	6	
	weathering, mold growth	3	
	compatibility w/existing paint	1	
	low quality	1	11
Fire Alarms	tripping	1	1
Flooring (slab coverings, coatings), Floor systems, wood floor joists	moisture (removal of finishes)	3	
	some abuse, structural stress	1	
	excessive wear	1	
	installation	2	
	squeaks - stress	1	
	seals	1	9
Foam roofing	improper installation	1	1
Forming Lumber	moisture	1	
	poor retention of finish	1	
	weathering	1	
	mechanical stresses	1	
	structural overload	1	5

TOTAL			
Building Component	**Durability Problem**	**Problem Count**	**Number of times Component Mentioned**
Framing - wood/structural, #2 white pine, dimensional lumber, lumber, wood, framing material, utility fir	termites	3	
	knots	1	
	rotting	1	
	moisture	5	
	wane	1	
	warp/twist	5	16
Hardware (hinges, locksets, closers)	under specification of quality based on use	2	
	poor design	1	
	abuse by military personnel	1	4
Hollow Core Wood Doors	warp (due to moisture)	1	1
Housing	moisture, weathering	1	
	insects	1	2
HVAC Systems including boilers (heating, ventilating, air cond.)	corrosion and early failure	3	
	poor maintenance	2	
	mechanical, poor maintenance	2	
	steam leaks	1	
	improper installation	1	
	poor design, high maintenance	1	10
Kitchen countertops	moisture, fungal decay	1	1
Mechanical Systems	poor designs	1	1
Metal products (AC units, fans, diffusers, storage tanks, plumbing fixtures, studs, steel doors, architectural, etc.)	corrosion from salt air, inside & outside	6	
	bad connections to metal frame	1	
	improper installation	1	
	water leaks (plumbing)	2	10
OSB	moisture	1	1
Paint	poor retention of finish	1	1
PT Plates	insects	1	1
Roofing /Flashing /Fascia /Soffit /Trusses /W.P. Membranes	installation, poor design (improper flashing)	12	
	Water Leakage	11	
	weathering (wind, UV)	7	
	insufficient funds to replace at end of svc life	3	
	insects, termites	2	
	poor retention of finish	2	
	moisture	3	
	mold	1	
	poor design	1	
	flange	1	
	valley - design	1	
	valley - installation	1	
	engineering	1	
	fungal decay	1	47
Showers - tile floors	moisture	1	2

TOTAL			
Building Component	**Durability Problem**	**Problem Count**	**Number of times Component Mentioned**
	installation	1	
Siding products (metal, wood, vinyl, composite)	Mold, mildew	1	
	wind damage	1	
	occupant damage	1	
	weathering, metal corrosion, mildew, paint adherence	1	
	improper installation	1	
	breakage	1	
	warping/cupping	1	
	fading of color	1	
	expansion	1	
	poor retention of finish	2	11
Steel	deflection, fireproofing	1	1
Stock Lumber	warping	1	1
Studs	twist and warp	1	1
Vinyl Floor Covering (linoleum)	damage (cuts during construction)	1	1
Vinyl Wallboard	moisture	1	
	mold	1	2
Walls, exterior	extensive weathering	1	
	termites	1	2
Walls, interior (sheetrock or gypsum board)	leaks (improper finishes allow water infiltration)	3	
	physical damage, abuse	3	
	improper installation	1	
	mold, fungal damage	2	9
Water distribution system	insufficient funds to replace at end of svc life	1	1
Waterproofing (above ground)	exposure	1	1
Weathering	high heat	1	1
Wharves	weathering, salt corrosion	1	1
Windows, window flashing	poor design, installation	7	
	leaks, caulking	3	
	moisture	1	
	paint	1	
	condensation	2	
	rotting	1	
	wood sticking	1	
	glazing fogs due to moisture	1	17
Wood Columns	weathering	1	1

Table 85 – Top Three Durability Problems, Total

The following three tables show the insights of the respondents for each respective population, LnO's, Prime Contractors, and "Top 200+" Builders.

LnO			
Building Component	**Durability Problem**	**Problem Count**	**Number of times Component Mentioned**
Brick veneer	lack of maintenance, old age	1	1
Carpet, ceramic tile	improper installation	1	
	quick to wear out	1	2
Concrete or masonry	steel corrosion	2	
	shrinkage/expansion/settlement	2	4
Doors, exterior (wood or metal)	moisture, weathering, rot	4	
	abuse - low resistance to rough use	1	5
Drywall, wallboard	Mold, mildew, fungal decay	3	
	does not withstand abuse from sailors/marines	2	5
Elevators	mechanical breakdown/stresses	2	
	poor design, installation	1	3
Exposed Steel (steel studs)	Rusting, ltd life span	2	2
Fiber reinforced stucco (EIFS)	improper installation	2	2
Finish coatings (paint)	application, maintenance (poor life cycle)	6	
	weathering, mold growth	3	
	compatibility w/existing paint	1	
	low quality	1	11
Flooring (slab coverings, coatings)	moisture (removal of finishes)	2	
	some abuse, structural stress	1	
	excessive wear	1	
	installation	1	5
Foam roofing	improper installation	1	1
Framing - wood/structural	termites	2	2
Hardware (hinges, locksets, closers)	under specification of quality based on use	2	
	poor design	1	3
Housing	moisture, weathering	1	
	insects	1	2
HVAC Systems including boilers (heating, ventilating, air cond.)	corrosion and early failure	3	
	poor maintenance	2	
	mechanical, poor maintenance	2	
	steam leaks	1	8
Kitchen countertops	moisture, fungal decay	1	1
Metal products (AC units, fans, diffusers, storage tanks, plumbing fixtures, studs, steel doors, architectural, etc.)	corrosion from salt air, inside & outside	6	
	bad connections to metal frame	1	
	improper installation	1	
	water leaks (plumbing)	1	9
Roofing /Flashing /Fascia /Soffit /Trusses /W.P. Membranes	installation, poor design (improper flashing)	12	32
	Water Leakage	10	
	weathering (wind, UV)	6	
	insufficient funds to replace at end of svc life	3	

LnO			
Building Component	**Durability Problem**	**Problem Count**	**Number of times Component Mentioned**
	insects, termites	1	
Siding products (metal, wood, vinyl)	Mold, mildew	1	
	wind damage	1	
	occupant damage	1	
	weathering, metal corrosion, mildew, paint adherence	1	4
Walls, exterior	extensive weathering	1	
	termites	1	2
Walls, interior (sheetrock or gypsum board)	leaks (improper finishes allow water infiltration)	3	
	physical damage, abuse	3	
	mold, fungal damage	1	7
Water distribution system	insufficient funds to replace at end of svc life	1	1
Wharves	weathering, salt corrosion	1	1
Windows	poor design, installation	2	
	leaks, caulking	1	
	glazing fogs due to moisture	1	4

Table 86 – Top Three Durability Problems, LnO

Prime Contractors			
Building Component	**Durability Problem**	**Problem Count**	**Number of times Component Mentioned**
Beams	crack and twist	1	1
Carpet	poor design	1	
	improper installation	1	
	wear from use	1	3
Concrete	cracking	1	1
Controls	lack of maintenance	1	1
Decks	moisture	1	
	weathering	1	2
Drywall	mechanical stresses	1	1
EIFS	weathering	1	
	poor design	1	2
Entry locksets	abuse by military personnel	1	1
Finger-Joint Wood Trim	de-lam	1	
	too noticeable	1	2
Fire Alarms	tripping	1	1
Flooring (slab coverings, coatings)	seals	1	1
Forming Lumber	moisture	1	5
	poor retention of finish	1	
	weathering	1	
	mechanical stresses	1	

Prime Contractors			
Building Component	Durability Problem	Problem Count	Number of times Component Mentioned
	structural overload	1	
Framing Lumber	warp/twist	1	1
Hollow Core Wood Doors	warp (due to moisture)	1	1
HVAC System	poor design, high maintenance	1	1
Mechanical Systems	poor design	1	1
PT Plates	insects	1	1
Roofing / Flashing /Fascia / Soffit / trusses / W.P. Membranes	leaks	1	
	weathering	1	
	poor retention of finish	1	
	moisture	1	4
Siding	improper installation	1	
	poor retention of finish	1	2
Steel	deflection, fireproofing	1	1
Stock lumber	warping	1	1
Studs	twist and warp	1	1
Waterproofing (above grade)	exposure	1	1
Wood	termites	1	1
Wood siding	moisture	2	
	fungal decay	1	
	mold	1	
	poor retention of finish	1	
	termites	1	
	poor design	1	7

Table 87 – Top Three Durability Problems, Prime Contractors

"Top 200+"			
Building Component	Durability Problem	Problem Count	Number of Times Component Mentioned
# 2 white pine, dimensional lumber, lumber, wood, framing material, utility fir	knots	1	12
	rotting	1	
	warping	3	
	moisture	5	
	wane	1	
	twist	1	
windows, window flashing	wood sticking	1	13
	rotting	1	
	moisture	1	
	paint	1	
	poor design	3	
	leaks	2	
	improper installation	2	

<table>
<tr><th colspan="4">“Top 200+”</th></tr>
<tr><th>Building Component</th><th>Durability Problem</th><th>Problem Count</th><th>Number of Times Component Mentioned</th></tr>
<tr><td></td><td>condensation</td><td>2</td><td></td></tr>
<tr><td rowspan="4">doors, masonite doors, exterior door jamb</td><td>denting</td><td>1</td><td rowspan="4">4</td></tr>
<tr><td>rotting</td><td>1</td></tr>
<tr><td>warping</td><td>1</td></tr>
<tr><td>fungal decay</td><td>1</td></tr>
<tr><td>wood columns</td><td>weathering</td><td>1</td><td>1</td></tr>
<tr><td rowspan="2">brick chimney</td><td>improper flashing</td><td>1</td><td rowspan="2">2</td></tr>
<tr><td>weight of structure</td><td>1</td></tr>
<tr><td rowspan="2">showers- tile floor p??s</td><td>moisture</td><td>1</td><td rowspan="2">2</td></tr>
<tr><td>installation</td><td>1</td></tr>
<tr><td>vinyl floor covering (linoleum)</td><td>damage (cuts during construction</td><td>1</td><td>1</td></tr>
<tr><td rowspan="2">gypsum wall board (sheet rock), gypsum</td><td>mold</td><td>1</td><td rowspan="2">2</td></tr>
<tr><td>improper installation</td><td>1</td></tr>
<tr><td rowspan="3">exterior woodwork</td><td>moisture</td><td>1</td><td rowspan="3">3</td></tr>
<tr><td>expansion</td><td>1</td></tr>
<tr><td>poor retention of finish</td><td>1</td></tr>
<tr><td rowspan="3">floor systems, wood floor joists</td><td>squeaks - stress</td><td>1</td><td rowspan="3">3</td></tr>
<tr><td>installation</td><td>1</td></tr>
<tr><td>moisture</td><td>1</td></tr>
<tr><td rowspan="4">roof leaks, roof system</td><td>flange</td><td>1</td><td rowspan="4">4</td></tr>
<tr><td>valley - design</td><td>1</td></tr>
<tr><td>valley - installation</td><td>1</td></tr>
<tr><td>engineering</td><td>1</td></tr>
<tr><td rowspan="2">composite wood</td><td>moisture</td><td>1</td><td rowspan="2">2</td></tr>
<tr><td>poor retention of finish</td><td>1</td></tr>
<tr><td rowspan="3">concrete, concrete foundation</td><td>weathering</td><td>1</td><td rowspan="3">3</td></tr>
<tr><td>improper installation</td><td>1</td></tr>
<tr><td>structural</td><td>1</td></tr>
<tr><td rowspan="2">drywall</td><td>improper installation</td><td>1</td><td rowspan="2">2</td></tr>
<tr><td>mold/mildew</td><td>1</td></tr>
<tr><td rowspan="5">exterior siding, vinyl siding, siding, wood siding (composite)</td><td>poor retention of finish</td><td>1</td><td rowspan="5">5</td></tr>
<tr><td>expansion</td><td>1</td></tr>
<tr><td>fading of color</td><td>1</td></tr>
<tr><td>breakage</td><td>1</td></tr>
<tr><td>warping/cupping</td><td>1</td></tr>
<tr><td>HVAC</td><td>improper installation</td><td>1</td><td>1</td></tr>
<tr><td rowspan="2">vinyl wallboard</td><td>moisture</td><td>1</td><td rowspan="2">2</td></tr>
<tr><td>mold</td><td>1</td></tr>
<tr><td>ABS - tubs and showers</td><td>crack</td><td>1</td><td>1</td></tr>
<tr><td>plumbing crimp rings</td><td>leaking</td><td>1</td><td>1</td></tr>
<tr><td>carpet</td><td>wear</td><td>1</td><td>1</td></tr>
<tr><td>OSB</td><td>moisture</td><td>1</td><td>1</td></tr>
</table>

"Top 200+"			
Building Component	Durability Problem	Problem Count	Number of Times Component Mentioned
paint	poor retention of finish	1	1
weathering	high heat	1	1
exterior sheathing	water/mold problem	1	1
bearing wall	structural	1	1

Table 88 – Top Three Durability Problems, "Top 200+"

Durability Perceptions by Component – LNO's, Prime Contractors, & "Top 200+" Builders

Respondents were asked to rate their perceptions of durability of various building components. I-joists were ranked highest (mean = 4.18) followed by Beams/Headers (mean = 4.15) by the Total of all populations. Each individual population also ranked these two components as the top two building components. Roofing (mean = 2.92) was rated as having the lowest durability by the combined populations. The following tables summarize the responses for Total, LnO's, Prime Contractors, and "Top 200+" Builders.

Total									
Building Component	N	0 - low durability	1	2	3	4	5 - high durability	Mean	Std. Deviation
I -joists	72			1	8	40	23	4.18	0.68
Beams/Headers	71				11	38	22	4.15	0.67
Roof Trusses	71			3	8	43	17	4.04	0.73
Moldings	72			2	22	42	6	3.72	0.65
Wall Framing	70		1	9	11	37	12	3.71	0.95
Sill Plates	72			4	23	38	7	3.67	0.73
Bathroom Cabinets	71			9	18	34	10	3.63	0.88
Kitchen Cabinets	72		1	6	22	33	10	3.63	0.88
Window Lineals	69			4	27	32	6	3.58	0.74
Floor Underlayment	71		1	8	24	30	8	3.51	0.89
Interior Doors	72		2	5	27	33	5	3.47	0.84
Roof Sheathing	72		1	8	26	31	6	3.46	0.85
Fascia, Soffit, & Corners	72	1	1	8	30	26	6	3.35	0.94
Siding	70		2	7	32	23	6	3.34	0.88
Exterior Door Framing	71	1	2	9	34	20	5	3.20	0.95
Deck Boards/Stair Treads	70	1	2	11	30	22	4	3.17	0.96
Fencing	66		3	11	28	20	4	3.17	0.94
Deck Railing Systems	70		3	14	28	20	5	3.14	0.97
Roofing	71		11	15	20	19	6	2.92	1.20
Other - Exterior Sheathing	1			1				2.00	0.00

Table 89 – Ranked Perceptions of Durability for Building Components, Total

LnO									
Building Component	**N**	**0 - low durability**	**1**	**2**	**3**	**4**	**5 - high durability**	**Mean**	**Std. Deviation**
I -joists	37			1	4	22	10	4.11	0.70
Beams/Headers	37				6	24	7	4.03	0.60
Roof Trusses	37			3	4	22	8	3.95	0.81
Wall Framing	37			5	4	21	7	3.81	0.91
Moldings	37			1	13	19	4	3.70	0.70
Window Lineals	36			2	15	18	1	3.50	0.65
Siding	37			1	19	15	2	3.49	0.65
Sill Plates	37			3	15	17	2	3.49	0.73
Bathroom Cabinets	37			8	9	15	5	3.46	0.99
Floor Underlayment	36		1	4	12	16	3	3.44	0.91
Kitchen Cabinets	37		1	6	12	13	5	3.41	1.01
Roof Sheathing	37		1	4	13	18	1	3.38	0.83
Interior Doors	37		2	3	14	15	3	3.38	0.95
Fascia, Soffit, & Corners	37			5	19	11	2	3.27	0.77
Exterior Door Framing	36		1	6	16	12	1	3.17	0.85
Fencing	37		1	8	16	11	1	3.08	0.86
Deck Railing Systems	37		2	9	14	9	3	3.05	1.03
Deck Boards/Stair Treads	37	1	2	7	14	11	2	3.03	1.09
Roofing	37		9	8	12	8		2.51	1.10

Table 90 – Ranked Perceptions of Durability for Building Components, LnO

Prime Contractors									
Building Component	**N**	**0 - low durability**	**1**	**2**	**3**	**4**	**5 - high durability**	**Mean**	**Std. Deviation**
I -joists	12				3	6	3	4.00	0.74
Beams/Headers	12				4	4	4	4.00	0.85
Roof Trusses	12				2	9	1	3.92	0.51
Sill Plates	12				4	7	1	3.75	0.62
Wall Framing	12			2	2	6	2	3.67	0.98
Exterior Door Framing	12				7	3	2	3.58	0.79
Kitchen Cabinets	12				6	5	1	3.58	0.67
Floor Underlayment	12			1	5	5	1	3.50	0.80
Bathroom Cabinets	12			1	5	5	1	3.50	0.80
Moldings	12			1	4	7		3.50	0.67
Window Lineals	11			2	4	3	2	3.45	1.04
Deck Boards/Stair Treads	11			1	6	4		3.27	0.65
Fencing	11			2	4	5		3.27	0.79
Roof Sheathing	12			2	6	3	1	3.25	0.87
Interior Doors	12			2	6	3	1	3.25	0.87
Fascia, Soffit, & Corners	12			2	6	3	1	3.25	0.87
Deck Railing Systems	12			3	4	5		3.17	0.83
Siding	11			3	6	2		2.91	0.70
Roofing	11		1	5	3	1	1	2.64	1.12

Table 91 – Ranked Perceptions of Durability for Building Components, Prime Contractors

"Top 200+"									
Building Component	**N**	**0 - low durability**	**1**	**2**	**3**	**4**	**5 - high durability**	**Mean**	**Std. Deviation**
Beams/Headers	22				1	10	11	4.45	0.60
I -joists	23				1	12	10	4.39	0.58
Roof Trusses	22				2	12	8	4.27	0.63
Kitchen Cabinets	23				4	15	4	4.00	0.60
Bathroom Cabinets	22				4	14	4	4.00	0.62
Sill Plates	23			1	4	14	4	3.91	0.73
Moldings	23				5	16	2	3.87	0.55
Window Lineals	22				8	11	3	3.77	0.69
Interior Doors	23				7	15	1	3.74	0.54
Roof Sheathing	23			2	7	10	4	3.70	0.88
Roofing	23		1	2	5	10	5	3.70	1.06
Floor Underlayment	23			3	7	9	4	3.61	0.94
Wall Framing	21		1	2	5	10	3	3.57	1.03
Fascia, Soffit, & Corners	23	1	1	1	5	12	3	3.52	1.20
Deck Boards/Stair Treads	22			3	10	7	2	3.36	0.85
Siding	22		2	3	7	6	4	3.32	1.21
Deck Railing Systems	21		1	2	10	6	2	3.29	0.96
Fencing	18		2	1	8	4	3	3.28	1.18
Exterior Door Framing	23	1	1	3	11	5	2	3.04	1.15
Other - Exterior Sheathing	1			1				2.00	0.00

Table 92 – Ranked Perceptions of Durability for Building Components, "Top 200+"

When comparing the durability ratings of building components between the individual populations it is seen that their perceptions are statistically significantly different based on a 0.10 significance level using ANOVA for the following building components: Beams/Headers, Roofing, Sill Plates, Kitchen Cabinets, and Bathroom Cabinets. This is summarized in the table below.

Building Component	Total	LnO	Prime Contractors	“Top 200+”	Sig.
I -joists	4.18	4.11	4.00	4.39	0.175
Beams/Headers	4.15	4.03	4.00	4.45	**0.038**
Roof Trusses	4.04	3.95	3.92	4.27	0.201
Moldings	3.72	3.70	3.50	3.87	0.279
Wall Framing	3.71	3.81	3.67	3.57	0.648
Sill Plates	3.67	3.49	3.75	3.91	**0.080**
Kitchen Cabinets	3.63	3.41	3.58	4.00	**0.036**
Bathroom Cabinets	3.63	3.46	3.50	4.00	**0.062**
Window Lineals	3.58	3.50	3.45	3.77	0.329
Floor Underlayment	3.51	3.44	3.50	3.61	0.793
Interior Doors	3.47	3.38	3.25	3.74	0.163
Roof Sheathing	3.46	3.38	3.25	3.70	0.248
Fascia, Soffit, & Corners	3.35	3.27	3.25	3.52	0.562
Siding	3.34	3.49	2.91	3.32	0.162
Exterior Door Framing	3.20	3.17	3.58	3.04	0.273
Deck Boards/Stair Treads	3.17	3.03	3.27	3.36	0.406
Fencing	3.17	3.08	3.27	3.28	0.710
Deck Railing Systems	3.14	3.05	3.17	3.29	0.684
Roofing	2.92	2.51	2.64	3.70	**0.000**

Table 93 – Comparison of Durability Perceptions

Additionally, building component durability ratings were broken down by job title and region for the LnO population. This can be seen in the following two tables.

The table below displays rankings of building component durability for each of the four respondent job titles. Building components are sorted by overall mean for each component. The highest four ratings within each job title appear as bold and underlined.

Building Component	Engineer	Facility Maintenance Supervisor	Architect	Construction Administration	Mean for Component
I joists	**<u>4.40</u>**	3.83	**<u>4.00</u>**	**<u>4.11</u>**	4.11
Beams/headers	**<u>4.20</u>**	**<u>4.00</u>**	**<u>4.00</u>**	**<u>3.89</u>**	4.03
Roof trusses	**<u>4.10</u>**	**<u>4.17</u>**	**<u>3.83</u>**	3.78	3.95
Wall Framing	**<u>4.20</u>**	3.67	3.50	**<u>3.89</u>**	3.81
Moldings	3.80	3.83	3.50	3.78	3.70
Window lineals	3.33	3.67	**<u>3.58</u>**	3.44	3.50
Sill plates	3.40	3.33	3.33	**<u>3.89</u>**	3.49
Siding	3.30	3.83	3.42	3.56	3.49
Bathroom cabinets	3.40	**<u>4.00</u>**	3.17	3.56	3.46
Floor underlayment	3.22	3.83	3.17	3.78	3.44
Kitchen cabinets	3.40	**<u>4.00</u>**	3.08	3.44	3.41
Interior doors	3.70	3.67	2.83	3.56	3.38
Roof sheathing	3.50	3.50	3.25	3.33	3.38
Fascia, soffit, corners	3.30	3.50	3.25	3.11	3.27
Exterior door framing	3.00	3.17	3.42	3.00	3.17
Fencing	2.70	3.17	3.00	3.56	3.08
Deck railing systems	3.10	3.33	2.75	3.22	3.05
Deck boards/stair treads	3.00	2.83	2.83	3.44	3.03
Roofing	2.10	2.67	2.75	2.56	2.51

Table 94 – Ranked Perceptions of Durability for Building Components by Job Title

Table 95 displays rankings of building component durability for each of the four respondent regions. Building components are sorted by overall mean for each component. The highest four ratings within each region appear as bold and underlined.

Building Component	South	Southwest	Pacific/Northwest	Atlantic/Northeast	Mean for Component
I joists	**<u>4.11</u>**	**<u>3.93</u>**	**<u>3.83</u>**	**<u>4.63</u>**	4.11
Beams/headers	**<u>4.33</u>**	**<u>3.93</u>**	**<u>4.00</u>**	**<u>3.88</u>**	4.03
Roof trusses	**<u>4.33</u>**	**<u>3.86</u>**	3.50	**<u>4.00</u>**	3.95
Wall Framing	3.78	3.64	**<u>3.83</u>**	**<u>4.13</u>**	3.81
Moldings	3.89	**<u>3.71</u>**	3.50	3.63	3.70
Window lineals	**<u>4.00</u>**	3.50	3.50	3.00	3.50
Siding	3.22	3.50	**<u>3.83</u>**	3.50	3.49
Sill plates	3.56	3.29	3.67	3.63	3.49
Bathroom cabinets	3.56	3.50	3.67	3.13	3.46
Floor underlayment	3.63	3.29	3.50	3.50	3.44
Kitchen cabinets	3.33	3.57	3.50	3.13	3.41
Interior doors	3.33	3.29	3.67	3.38	3.38
Roof sheathing	3.44	3.29	3.50	3.38	3.38
Fascia, soffit, corners	3.33	3.29	3.17	3.25	3.27
Exterior door framing	3.13	3.14	2.83	3.50	3.17
Fencing	3.22	2.79	3.50	3.13	3.08
Deck railing systems	3.00	2.93	3.50	3.00	3.05
Deck boards/stair treads	3.11	2.64	3.67	3.13	3.03
Roofing	2.11	2.71	2.67	2.50	2.51

Table 95 – Ranked Perceptions of Durability for Building Components by Region

For any of the above building components rated lower than 3 on a scale of 0 = low durability to 5 = high durability, all respondents indicated the type of durability problems as follows in the table below followed by tables for each individual population:

TOTAL			
Building Component	**Problem**	**Count**	**Count per Component**
Wall framing	weathering, rust	3	
	insects, termites	3	
	poor design, installation	1	
	fungal decay	2	
	warp/twist	3	
	bowed studs	1	
	mold	1	
	moisture	1	15
I joists	weathering, corrosion	1	
	insects	1	
	fungal decay	1	
	spalling precast I beams	1	4
Beams/headers	warping	1	
	poor design	1	2
Roofing	moisture, leaks	12	
	weathering, steel decking corrosion	9	
	poor design, installation	7	
	mechanical stress	9	
	insects	1	
	fire	1	
	never meets rated endurance	1	
	improper installation	1	
	noticeable sagging/joints	1	
	lack of maintenance	1	43
Roof trusses	poor design, overstress	1	
	noticeable sagging/joints	1	
	improper installation	1	
	leaks (causes low durability)	1	
	insects	2	6
Roof sheathing	moisture, leaks	8	
	insects	1	
	noticeable sagging/joints	1	
	improper installation	1	
	OSB edge swell	1	
	birth defects	1	13
Floor underlayment	moisture, warp	5	
	OSB edge swell	1	
	poor installation	1	
	poor design	1	8
Interior doors	swells w/humidity	1	6

TOTAL			
Building Component	**Problem**	**Count**	**Count per Component**
	delamination - hinges	1	
	damage by personnel	1	
	hardware problems	1	
	internal construction inadequate	1	
	ow resistance to rough usage	1	
Exterior door framing	moisture	4	
	weathering, corrosion from salt air	8	
	insects	1	
	studs rot	1	
	jambs rot	2	
	warping	1	
	paint finish	1	
	poor design	1	
	decay in sill area	1	
	poor finish coating	1	
	security entrance wear & tear	1	22
Window lineals	poor specs/installation	2	
	paint, moisture, weathering	1	
	finish problems	1	
	moisture	1	5
Siding	weathering	2	
	improper installation	1	
	moisture	6	
	paint retention	2	
	warping	1	
	too hot here	1	
	paint	2	15
Fascia, soffit, corners	Sun Exposure, drying	1	
	Moisture penetration, weathering	8	
	Loss of coating protection of metals w/corrosion	1	
	water	1	
	rotting	1	
	paint retention	2	
	insects	2	16
Deck boards/stair treads	rubber stair tread delamination	1	
	installation (tread attachment)	1	
	Loss of coating protection of metals w/corrosion	1	
	Moisture penetration, rot, warp, bowing	7	
	weathering	2	
	finish	1	
	Sun Exposure, drying	2	15
Deck railing systems	Loss of coating protection of metals w/corrosion (rust at posts)	2	18
	Moisture penetration, rot, warp, bowing, rust	8	
	poor finish coating	1	

TOTAL			
Building Component	Problem	Count	Count per Component
	finish	1	
	mechanical stress	1	
	vinyl	1	
	weathering	2	
	Sun Exposure, drying	2	
Sill plates	Sun Exposure, drying	1	
	insects	1	
	Moisture penetration	5	7
Kitchen cabinets	termites	1	
	did not stand up to use (durability)	3	
	poor specifications	2	
	hinges	1	
	edge swell	1	
	moisture	1	9
Bathroom cabinets	did not stand up to use (durability)	3	
	poor specifications	2	
	high durability unless leak in bathroom	1	
	lacquer frosting	1	
	moisture	2	9
Fencing	Sun Exposure, drying	1	
	Moisture, weathering, rot	8	
	Loss of coating protection of metals w/corrosion	1	
	poor design	1	
	expense	1	
	P.T. material not holding up	1	
	paint/stain retention	1	
	vinyl	1	
	poor material	1	
	insects	1	17
Moldings	N/A		0

Table 96 –Building Component Durability Problems, Total

LnO			
Building Component	Problem	Count	Count per component
Wall framing	weathering, rust	3	
	insects	2	
	poor design, installation	1	
	fungal decay	2	
	moisture	1	9
I joists	weathering, corrosion	1	
	insects	1	
	fungal decay	1	
	spalling precast I beams	1	4

LnO			
Building Component	**Problem**	**Count**	**Count per component**
Beams/headers	poor design	1	1
	moisture, leaks	9	
	weathering, steel decking corrosion	4	
	poor design, installation	6	
	mechanical stress	9	
	insects	1	
Roofing	lack of maintenance	1	30
	poor design, overstress	1	
Roof trusses	insects	2	3
	moisture, leaks	4	
	insects	1	
Roof sheathing	birth defects	1	6
	moisture, warp	4	
Floor underlayment	poor design	1	5
	swells w/humidity	1	
	delamination - hinges	1	
Interior doors	low resistance to rough usage	1	3
	moisture	3	
	weathering, corrosion from salt air	8	
	insects	1	
Exterior door framing	security entrance wear & tear	1	13
	poor specs/installation	2	
Window lineals	moisture	1	3
Siding	N/A		0
	Sun Exposure, drying	1	
	Moisture penetration, weathering	4	
	Loss of coating protection of metals w/corrosion	1	
Fascia, soffit, corners	insects	2	8
	rubber stair tread delamination	1	
	installation (tread attachment)	1	
	Loss of coating protection of metals w/corrosion	1	
	Moisture penetration, rot, warp, bowing	4	
Deck boards/stair treads	Sun Exposure, drying	2	9
	Loss of coating protection of metals w/corrosion (rust at posts)	2	
	Moisture penetration, rot, warp, bowing, rust	6	
Deck railing systems	Sun Exposure, drying	2	10
	Sun Exposure, drying	1	
Sill plates	Moisture penetration	3	4
Kitchen cabinets	termites	1	8
	did not stand up to use (durability)	3	
	poor specifications	2	
	hinges	1	

LnO			
Building Component	Problem	Count	Count per component
	moisture	1	
	did not stand up to use (durability)	3	
	poor specifications	2	
Bathroom cabinets	moisture	1	6
	Sun Exposure, drying	1	
	Moisture, weathering, rot	6	
	Loss of coating protection of metals w/corrosion	1	
	poor design	1	
	expense	1	
Fencing	insects	1	11
Moldings	N/A		0

Table 97 –Building Component Durability Problems, LnO

Prime Contractors			
Building Component	Problem	Count	Count per component
	warping	1	
Wall framing	warp/twist	1	2
I joists	N/A		0
Beams/headers	N/A		0
	moisture, leaks	2	
	fire	1	
	weathering	4	
	improper installation	1	
	never meets rated endurance	1	
Roofing	noticeable sagging/joints	1	10
	leaks (causes low durability)	1	
	noticeable sagging/joints	1	
Roof trusses	improper installation	1	3
	leaks (causes low durability)	2	
	noticeable sagging/joints	1	
Roof sheathing	improper installation	1	4
Floor underlayment	N/A		0
	damage by personnel	1	
	hardware problems	1	
Interior doors	internal construction inadequate	1	3
Exterior door framing	poor finish coating	1	1
Window lineals	paint, moisture, weathering	1	1
	paint	2	
	weathering	2	
	moisture	2	
Siding	improper installation	1	7
Fascia, soffit, corners	water	1	2

	weathering	1	
Deck boards/stair treads	weathering	1	1
Deck railing systems	poor finish coating	1	1
	insects	1	
Sill plates	moisture	1	2
Kitchen cabinets	N/A		0
	moisture	1	
Bathroom cabinets	high durability unless leak in bathroom	1	2
	weathering	1	
Fencing	P.T. material not holding up	1	2
Moldings	N/A		0

Table 98 –Building Component Durability Problems, Prime Contractors

"Top 200+" Builders			
Building Component	**Problem**	**Count**	**Count per component**
	warp	1	
	mold	1	
	bowed studs	1	
Wall framing	termites	1	4
I joists	N/A		0
Beams/headers	warping	1	1
	valley and collar leaks	1	
	weathering	1	
Roofing	poor design	1	3
Roof trusses	N/A		0
	OSB edge swell	1	
Roof sheathing	moisture	2	3
	OSB edge swell	1	
	poor installation	1	
Floor underlayment	moisture	1	3
Interior doors	N/A		0
	studs rot	1	
	moisture	1	
	jambs rot	2	
	warping	1	
	paint finish	1	
	poor design	1	
Exterior door framing	decay in sill area	1	8
Window lineals	finish problems	1	1
	moisture	4	
	paint retention	2	
	warping	1	
Siding	too hot here	1	8
Fascia, soffit, corners	rotting	1	6
	moisture	3	

“Top 200+” Builders			
Building Component	Problem	Count	Count per component
	paint retention	2	
Deck boards/stair treads	weathering	1	5
	warping	2	
	finish	1	
	moisture	1	
Deck railing systems	moisture	1	7
	weathering	2	
	finish	1	
	warping	1	
	mechanical stress	1	
	vinyl	1	
Sill plates	moisture	1	1
Kitchen cabinets	edge finish	1	1
Bathroom cabinets	lacquer frosting	1	1
Fencing	paint/stain retention	1	4
	poor material	1	
	vinyl	1	
	weather	1	
Moldings	N/A		0

Table 99 –Building Component Durability Problems, “Top 200+”

Additional applications mentioned by the Prime Contractors population:

Application	Durability	Problem, if any
Locksets	Not rated	damage by personnel
slate roofing	5 – high durability	
singles 4/12 p	1 – low durability	
aluminum soffit	5 – high durability	

Table 100 – Additional Application Durability Rankings, Prime Contractors

Additional applications mentioned by the “Top 200+” Builders population:

Application	Durability	Problem, if any
Exterior Sheathing	2	mold

Table 101 – Additional Application Durability Rankings, “Top 200+”

Warranty/Complaint Problems

Top 3 Problems – Wholesalers & Retailers

The table below displays the respondents’ from the Wholesalers and Retailers insights regarding warranty problems with the three most problematic building components.

Total			
Building Component	Warranty Problem	Problem Count	Number of Times Component Mentioned
Cabinets, kitchen cabinets	Knots & Misc. defects	1	2
	Damage	1	
Carpet	Color	1	1
Cedar, Cedar shingles and trim, Cedar siding	Tannin bleed	1	3
	Extractive bleeding	1	
	Tanic acid bleeding	1	
Composite products, composite siding	color match	1	3
	Decomposes with environmental exposure	1	
	Installation problems	1	
Concrete	Dusting	1	1
Decorative lights	plastic is weak and settles	1	1
Dimension Lumber, Framing Lumber	Termite Damage	1	6
	Mold issues	2	
	twist, warp, crook, wane	3	
Door Lites	seal failure	1	1
Doors, Entry Doors, Exterior Doors, wood doors, steel doors, Masonite Doors	installation, improper installation	4	18
	warping	4	
	air infiltration	1	
	leaks	3	
	Out of square	1	
	Breaks	1	
	Dents and Scratches	2	
	Rust	2	
Fingerjoint Redwood and Ceder	Glue voids at the joints	1	1
Floor Underlayment	delamination	1	1
Glass	seal failure	1	1
Glulams	Dry rot	1	1
Hardboard Siding	Claims so large there are class action suits	1	2
	Product deteriatiion	1	
Housewrap	Moisture vapor transmission	1	1
Lumber, lumber quarlity (visual), mold on lumber, yellow pine lumber	Doesn't look grade of stamp, off grade, grade	3	14
	instability	1	
	mold, mildew	3	
	warping, crook and twist	2	
	moisture	1	
	Product misrepresented	1	
	No Manufacturer's support	1	
	Bad STK	1	
	quality	1	
LVL's	sizing differences	1	1
OSB, OSB board	dlamination	1	11
	Wafing	1	
	buckling	1	

Total			
Building Component	Warranty Problem	Problem Count	Number of Times Component Mentioned
	edge swelling, swelling	8	
Plywood, plywood delamination, rated sheathing plywood	delamination	12	
	Bowing	1	
	buckling	3	
	manufacturing defects	1	
	No Manufacturer's support	1	
	Bad STK	1	19
Plywood and OSB flooring	Product OK does not get glued properly	1	1
Roof	shingles	1	1
Roof sheathing	buckling, delamination	1	1
Roofing	Installation	1	
	wind hail	1	
	Length	1	
	product failure	1	
	Blow-offs	1	
	not sealing	1	6
Roofing shingles, shingles, fiberglass shingles, asphalt roofing shingles, Heritage II shingles	Discoloration	1	
	curl ups	1	
	blow off	1	
	not sealing	2	
	color	1	
	poor tar strip	1	
	variation in size	1	
	Wind damage	1	9
Siding, pine siding	Finish problems, peeling, etc.	1	
	shrinks	1	
	application	1	
	installation	1	
	warping	2	
	delamination	1	7
Decking	Installation	1	1
Steel, CO2000 Building Steel	Rust	2	
	denting	1	
	Paint Problems	1	4
Steel siding	finish/paint failure	2	2
Studs, S-P-F studs, studs/wall framing	mold	1	
	Twisting and Warping	2	3
SYP sheathing, wall sheathing	delamination	1	
	damage	1	2
SYP treated decking	surface checking	1	1
Trex	they will not cover any warranty problems	1	1
Under layments	swelling	1	
	delamination	1	2

Total			
Building Component	Warranty Problem	Problem Count	Number of Times Component Mentioned
Vinyl, vinyl products, vinyl siding	structural stability	1	
	contraction and expansion due to hot and cold temperature	1	
	fading	3	
	melting (deflection)	1	
	nailed too tight, installation	2	
	buckle	1	9
White fir and spruce fasia	warping and cupping mainly 1" products	1	1
Windows, windows (glass), wood windows, replacement windows	Water leaks	3	
	seal failure	8	
	condensation, moisture in glass, fogged glass	3	
	glass, glass failure, insulated glass	3	
	Stress cracks	1	
	air leakage	2	
	installation	3	
	Breaks	1	
	proper Fit	1	25
Wood, wood products	Rot	2	
	Moisture	1	
	splitting	2	
	warping, cupping	2	
	stains	1	
	maintenance	1	9
Wood flooring and doors	Warping - Excessive Shrink	1	1
Wood Siding/Paint	bleed through	1	
	peeling	1	
	fungus	1	3
WPC decking	rot	1	
	Improper installation	1	2

Table 102 – Top Three Warranty Problems, Total

Customer Complaint Volume by Component – Wholesalers & Retailers

Respondents from the Wholesalers and Retailers populations were asked to rate their company's customer complaint volume on a scale from 0 = no customer complaints to 5 = many customer complaints for a list products. The product with the greatest complaint volume was Windows (mean = 1.95) while the product complained about the least was Sill Plates (mean = 0.59). Tables illustrating the complaint volume for the total population then each individual population can be seen below.

Total									
Product	N	0 - No Complaints	1	2	3	4	5 - Many Complaints	Mean	Std. Dev.
Windows	58	4	21	18	9	1	5	1.95	1.29
Siding	63	8	25	16	12		2	1.63	1.13
Floor underlayment	57	11	22	16	7	1		1.39	1.00
Deck boards/stair treads	62	17	22	14	7	2		1.27	1.09
Exterior door framing	58	14	28	9	5	1	1	1.21	1.07
Roof Sheathing	60	13	32	8	6	1		1.17	0.94
Deck railing systems	61	22	26	9	3	1		0.93	0.93
Moldings	60	24	24	9	3			0.85	0.86
Fascia, soffit, & corners	64	29	27	5	3			0.72	0.81
Fencing	54	24	25	3	1	1		0.70	0.82
Sill plates	56	30	21	3	2			0.59	0.76
Other - Doors	1						1	5.00	0.00
Other - Trex	1					1		4.00	0.00
Other - Flooring	1				1			3.00	0.00
Other - Wall Framing	2			1	1			2.50	0.71
Other - Wallboard	1			1				2.00	0.00

Table 103 – Complaint Volume by Product, Total

Wholesalers									
Product	N	0 - No Complaints	1	2	3	4	5 - Many Complaints	Mean	Std. Dev.
Windows	21	3	7	5	3	1	2	1.90	1.48
Siding	27	3	11	7	5		1	1.67	1.14
Exterior door framing	21	7	7	3	3	1		1.24	1.22
Floor underlayment	21	7	7	5	2			1.10	1.00
Roof Sheathing	24	7	14	1	2			0.92	0.83
Deck boards/stair treads	25	10	10	3	2			0.88	0.93
Deck railing systems	25	10	10	4	1			0.84	0.85
Moldings	23	13	5	4	1			0.70	0.93
Fascia, soffit, & corners	27	14	9	3	1			0.67	0.83
Fencing	22	11	9	2				0.59	0.67
Sill plates	20	12	6	1	1			0.55	0.83
Other - Doors	1						1	5.00	0.00
Other - Trex	1					1		4.00	0.00
Other - Wallboard	1			1				2.00	0.00

Table 104 – Complaint Volume by Product, Wholesalers

Retailers									
Product	N	0 - No Complaints	1	2	3	4	5 - Many Complaints	Mean	Std. Dev.
Windows	37	1	14	13	6		3	1.97	1.19
Siding	36	5	14	9	7		1	1.61	1.13
Floor underlayment	36	4	15	11	5	1		1.56	0.97
Deck boards/stair treads	37	7	12	11	5	2		1.54	1.12
Roof Sheathing	36	6	18	7	4	1		1.33	0.99
Exterior door framing	37	7	21	6	2		1	1.19	1.00
Deck railing systems	36	12	16	5	2	1		1.00	0.99
Moldings	37	11	19	5	2			0.95	0.81
Fencing	32	13	16	1	1	1		0.78	0.91
Fascia, soffit, & corners	37	15	18	2	2			0.76	0.80
Sill plates	36	18	15	2	1			0.61	0.73
Other - Flooring	1				1			3.00	0.00
Other - Wall Framing	2			1	1			2.50	0.71

Table 105 – Complaint Volume by Product, Retailers

For applications rater higher than 3, respondents were asked to indicate the type of problem with that product. These results for the total population can be seen below.

TOTAL			
Product	**Problem**	**Count**	**Count per Component**
Roof sheathing	improper installation	1	1
Floor Underlayment	delamination	1	1
Framing	finger-joints separating	1	
	installation	2	
	out of square	1	
	paint peel	1	
	warping	1	6
Windows	air infiltration	1	
	installation	2	
	insulated glass, glass	2	
	locks	1	
	leaking	2	
	seal fail	3	11
Siding	bleed, cedar bleed	2	
	paint peel	1	
	fading problems	1	
	hardboard and OSB siding	1	
	installation	2	7
Fascia, Soffit, & Corners	bleed	1	
	paint peel	1	
	shrinkage	1	3
Deck Boards/Stair Treads	fading problems	1	
	too many choices	1	
	wet #2 boards	1	3
Deck Railing Systems	fading problems	1	1
Sill Plates	N/A	0	0
Fencing	post rotting	1	1
Moldings	profile not matching	1	
	shinkage	1	
	mismanufacture	1	3
Other - Trex	discolor	1	
	warp	1	2
Other - Doors	operation	1	1
Other - Flooring	shink	1	1
Other - Framing	mould?	1	1

Table 106 – Problems by Product, Total

Complaint Statement Agreement – Wholesalers & Retailers

Respondents from the Wholesalers and Retailers populations were asked to rate their agreement with statements concerning complaints on a scale from 1 = Strongly Disagree to 7 = Strongly Agree. They agreed most with the statement “Managing customer

complaints is important to my company." (mean = 6.68) and agreed least with the statement "Customer product complaints are a big problem at my company."

Population	Statement	N	1 - Strongly Disagree	2	3	4	5	6	7 - Strongly Agree	Mean	Std. Dev
Total	Managing customer complaints is important to my company.	66	1				2	11	52	6.68	0.86
	Customer Product Complaints are a big problem at my company.	66	14	23	14	8	4	2	1	2.62	1.40
	The costs associated with customer complaints substantially impact my company's profitability.	66	6	25	11	5	7	7	5	3.35	1.83
Wholesalers	Managing customer complaints is important to my company.	29	1				1	4	23	6.59	1.18
	Customer Product Complaints are a big problem at my company.	29	8	9	6	1	3	1	1	2.62	1.63
	The costs associated with customer complaints substantially impact my company's profitability.	29	2	14	2	2	5	2	2	3.28	1.81
Retailers	Managing customer complaints is important to my company.	37					1	7	29	6.76	0.49
	Customer Product Complaints are a big problem at my company.	37	6	14	8	7	1	1		2.62	1.21
	The costs associated with customer complaints substantially impact my company's profitability.	37	4	11	9	3	2	5	3	3.41	1.86

Table 107 – Complaint Statement Agreement

Substitution Potential

Substitution Potential by Application – LNO's, Prime Contractors, "Top 200+" Builders, Wholesalers, & Retailers

Respondents from all five populations were asked to rate their perceptions of the potential for substituting woodfiber-plastic composites for various building components. As illustrated in the table below, Deck Railing Systems was ranked as having the highest substitution potential (mean = 3.88). Deck Boards/Stair Treads (mean = 3.86) and Fencing (mean = 3.56) were second and third respectively. I joists, Roof Trusses, and Beams/Headers were ranked as having the lowest substitution potential. They were also ranked as currently the most durable building components, as shown in the previous section. The following tables show the respondents perceptions of potential substitution of woodfiber-plastic composites for different building components as a whole, then as each individual population.

Total											
Building Component	**N**	**0 No potential**	**1**	**2**	**3**	**4**	**5 Most**	**6 Don't Know**	**n**	**Mean**	**Std. Dev.**
Deck railing systems	137	5	7	4	22	36	56	7	130	3.88	1.35
Deck boards/stair treads	140	4	9	7	21	35	59	5	135	3.86	1.37
Fencing	141	8	7	8	22	48	35	13	128	3.56	1.42
Molding	140	3	3	21	27	42	31	13	127	3.54	1.23
Fascia, soffit, corners	140	7	5	12	29	38	34	15	125	3.50	1.38
Exterior door framing	139	5	6	16	34	40	23	15	124	3.35	1.28
Siding	139	9	7	15	32	35	29	12	127	3.29	1.45
Interior doors	139	2	10	19	39	35	17	17	122	3.20	1.20
Window lineals	138	6	11	15	25	37	20	24	114	3.19	1.41
RTA Furniture	139	5	8	19	24	28	16	39	100	3.10	1.37
Sill plates	139	8	18	12	28	36	20	17	122	3.03	1.50
Floor underlayment	141	15	23	26	34	20	8	15	126	2.36	1.42
Bathroom cabinets	141	15	24	20	27	25	6	24	117	2.35	1.47
Kitchen cabinets	141	16	25	20	27	23	6	24	117	2.29	1.47
Roofing	140	17	24	23	25	22	5	24	116	2.22	1.46
Beams/headers	141	28	22	25	20	14	14	18	123	2.10	1.66
Roof sheathing	141	20	34	22	21	21	5	18	123	2.03	1.47
I joists	141	30	28	23	14	14	13	19	122	1.94	1.66
Roof trusses	141	28	37	20	12	16	9	19	122	1.82	1.58
Wall Framing	140	30	30	24	15	16	5	20	120	1.77	1.50
Other - Wall Framing "non-structural"	1					1			1	4.00	0.00

Table 108 – Ranked Substitution Potential, All Respondents, Total

LnO									
Building Component	**N**	**0 No potential**	**1**	**2**	**3**	**4**	**5 Most**	**Mean**	**Std. Dev.**
Molding	35	1	1	5	8	11	9	3.54	1.27
Fencing	35	3	3	1	5	14	9	3.46	1.56
Deck railing systems	34	3	3	1	7	12	8	3.35	1.55
Fascia, soffit, corners	35	2	3	3	9	9	9	3.34	1.47
Siding	35	4	3	4	4	10	10	3.23	1.72
RTA Furniture	34	3	1	5	8	11	6	3.21	1.45
Deck boards/stair treads	35	2	6	3	7	7	10	3.17	1.64
Interior doors	35	1	5	4	12	9	4	3.00	1.31
Kitchen cabinets	35	5	1	4	9	11	5	3.00	1.57
Bathroom cabinets	35	5	1	4	9	11	5	3.00	1.57
Exterior door framing	35	4	5	6	7	7	6	2.74	1.63
Floor underlayment	35	2	5	6	12	8	2	2.71	1.30
Sill plates	33	3	6	3	9	10	2	2.70	1.47
Window lineals	35	4	4	6	9	9	3	2.69	1.49
Roof sheathing	35	3	7	5	10	9	1	2.51	1.38
Roofing	35	7	7	7	5	9		2.06	1.49
Roof trusses	35	7	7	8	4	8	1	2.06	1.53
Wall Framing	35	8	6	7	6	7	1	2.03	1.54
Beams/headers	35	10	3	10	5	5	2	1.94	1.59
I joists	35	11	3	9	5	5	2	1.89	1.62

Table 109 – Ranked Substitution Potential, All Respondents, LnO

Prime Contractors											
Building Component	**N**	**0 No potential**	**1**	**2**	**3**	**4**	**5 Most**	**6 Don't Know**	**n**	**Mean**	**Std. Dev.**
Fascia, soffit, corners	14				1	8	1	4	10	4.00	0.47
Window lineals	13				1	7		5	8	3.88	0.35
Fencing	14			1	3	5	3	2	12	3.83	0.94
Deck railing systems	14				4	5	2	3	11	3.82	0.75
RTA Furniture	14				3	5	1	5	9	3.78	0.67
Deck boards/stair treads	14			1	5	4	3	1	13	3.69	0.95
Interior doors	14			1	3	8		2	12	3.58	0.67
Siding	14			2	3	5	2	2	12	3.58	1.00
Molding	14			2	5	3	2	2	12	3.42	1.00
Exterior door framing	14			3	2	6		3	11	3.27	0.90
Roofing	14			2	4	4		4	10	3.20	0.79
Sill plates	14			2	5	2	1	4	10	3.20	0.92
Floor underlayment	14			4	5	3		2	12	2.92	0.79
Wall Framing	14			5	3	2	1	3	11	2.91	1.04
Beams/headers	14			5	3	3		3	11	2.82	0.87
I joists	14			5	4	2		3	11	2.73	0.79
Roof sheathing	14		1	4	1	3		5	9	2.67	1.12
Kitchen cabinets	14		2	3	4	2		3	11	2.55	1.04
Bathroom cabinets	14		2	3	4	2		3	11	2.55	1.04
Roof trusses	14		1	5	3	1		4	10	2.40	0.84

Table 110 – Ranked Substitution Potential, All Respondents, Prime Contractors

Top 200											
Building Component	**N**	**0 No potential**	**1**	**2**	**3**	**4**	**5 Most**	**6 Don't Know**	**n**	**Mean**	**Std. Dev.**
Deck boards/stair treads	23	1	1	2	2	3	11	3	20	3.90	1.55
Deck railing systems	23		2	2	3	3	10	3	20	3.85	1.42
Exterior door framing	23		1	1	4	9	5	3	20	3.80	1.06
Fencing	23	1		2	2	7	5	6	17	3.71	1.36
Siding	23			3	4	9	3	4	19	3.63	0.96
Molding	23		1	4	3	6	5	4	19	3.53	1.26
Fascia, soffit, corners	23	2		2	4	7	4	4	19	3.37	1.50
Sill plates	23	1	2	2	3	7	4	4	19	3.32	1.49
Interior doors	22		1	3	7	6	2	3	19	3.26	1.05
Window lineals	22		4	2	2	5	2	7	15	2.93	1.49
RTA Furniture	22		1	2	5	1	1	12	10	2.90	1.10
Roofing	23		4	3	3	3	1	9	14	2.57	1.34
Floor underlayment	23	1	5	3	5	4	1	4	19	2.47	1.39
Roof sheathing	23		6	3	5	2	1	6	17	2.35	1.27
Bathroom cabinets	23	1	4	6	4	3		5	18	2.22	1.17
Wall Framing	23	3	4	1	4	3	1	7	16	2.19	1.64
Beams/headers	23	2	5	4	3	1	2	6	17	2.12	1.54
I joists	23	1	7	3	2	2	1	7	16	2.00	1.41
Kitchen cabinets	23	2	5	5	3	3		5	18	2.00	1.28
Roof trusses	23	2	7	3	2	1	2	6	17	1.94	1.56

Table 111 – Ranked Substitution Potential, All Respondents, "Top 200+"

Wholesalers											
Building Component	**N**	**0 No potential**	**1**	**2**	**3**	**4**	**5 Most**	**6 Don't Know**	**n**	**Mean**	**Std. Dev.**
Molding	28	1	1		3	10	6	7	21	4.36	1.47
RTA Furniture	29	1	1	5	3	3	2	14	15	4.34	1.91
Window lineals	28		1	2	5	7	6	7	21	4.29	1.41
Exterior door framing	27	1		2	6	7	5	6	21	4.11	1.50
Interior doors	28		1	4	7	3	6	7	21	4.07	1.56
Deck boards/stair treads	28	1	1	1	2	11	11	1	27	4.07	1.30
Deck railing systems	26	2		1	4	6	13		26	3.96	1.46
Fascia, soffit, corners	28	3	1	2	5	3	8	6	22	3.86	1.94
Sill plates	29	2	3	2	5	6	5	6	23	3.69	1.87
Fencing	29	3	2	2	3	7	8	4	25	3.69	1.87
Bathroom cabinets	29	4	3	3	4	6		9	20	3.41	2.18
Kitchen cabinets	29	4	3	3	5	5		9	20	3.38	2.18
Siding	27	4	2	3	7	2	5	4	23	3.19	2.00
Beams/headers	29	6	3	4	3	2	3	8	21	3.14	2.36
Floor underlayment	29	6	4	2	4	3	3	7	22	3.07	2.31
I joists	29	7	4	3	2	2	3	8	21	3.00	2.45
Roof trusses	29	7	5	3	1	2	3	8	21	2.93	2.48
Roofing	29	4	5	5	5	1	3	6	23	2.93	2.14
Roof sheathing	29	7	5	2	3	3	3	6	23	2.79	2.34
Wall Framing	29	8	5	4	1	3		8	21	2.62	2.44
Other - Wall Framing "non-structural"	1					1			1	4.00	0.00

Table 112 – Ranked Substitution Potential, All Respondents, Wholesalers

Retailers											
Building Component	**N**	**0 No potential**	**1**	**2**	**3**	**4**	**5 Most**	**6 Don't Know**	**n**	**Mean**	**Std. Dev.**
Deck boards/stair treads	40		1		5	10	24		40	4.40	0.90
Deck railing systems	40		2		4	10	23	1	39	4.38	1.05
Fascia, soffit, corners	40		1	5	10	11	12	1	39	3.78	1.17
Exterior door framing	40			4	15	11	7	3	37	3.75	1.10
Fencing	40	1	2	2	9	15	10	1	39	3.73	1.26
Window lineals	40	2	2	5	8	9	9	5	35	3.68	1.62
RTA Furniture	40	1	5	7	5	8	6	8	32	3.60	1.79
Siding	40	1	2	3	14	9	9	2	38	3.58	1.34
Interior doors	40	1	3	7	10	9	5	5	35	3.45	1.55
Molding	40	1		10	8	12	9		40	3.43	1.24
Sill plates	40	2	7	3	6	11	8	3	37	3.33	1.72
Roofing	39	6	8	6	8	5	1	5	34	2.54	1.90
Bathroom cabinets	40	5	14	4	6	3	1	7	33	2.48	2.05
Kitchen cabinets	40	5	14	5	6	2	1	7	33	2.43	2.04
Beams/headers	40	10	11	2	6	3	7	1	39	2.15	1.94
Floor underlayment	40	6	9	11	8	2	2	2	38	2.13	1.59
I joists	40	11	14	3	1	3	7	1	39	1.90	1.96
Roof trusses	40	12	17	1	2	4	3	1	39	1.55	1.74
Wall Framing	39	11	15	7	1	1	2	2	37	1.49	1.65
Roof sheathing	40	10	15	8	2	4		1	39	1.48	1.41

Table 113 – Ranked Substitution Potential, All Respondents, Retailers

When comparing the substitution ratings for woodfiber-plastic composites for various building components between the individual populations it is seen that their perceptions are statistically significantly different based on a 0.10 significance level using ANOVA for the following building components: Deck Railing Systems, Deck Boards/Stair Treads, Exterior Door Framing, Window Lineals, Floor Underlayment, Kitchen Cabinets, Roof Sheathing, and Wall Framing. This is summarized in the table below.

Building Component	Total	LnO	Prime	"Top 200+"	Wholesalers	Retailers	Sig.
Deck railing systems	3.88	3.35	3.82	3.85	3.96	4.38	**0.043**
Deck boards/stair treads	3.86	3.17	3.69	3.90	4.07	4.40	**0.003**
Fencing	3.56	3.46	3.83	3.71	3.69	3.73	0.788
Molding	3.54	3.54	3.42	3.53	4.36	3.43	0.834
Fascia, soffit, corners	3.50	3.34	4.00	3.37	3.86	3.78	0.485
Exterior door framing	3.35	2.74	3.27	3.80	4.11	3.75	**0.015**
Siding	3.29	3.23	3.58	3.63	3.19	3.58	0.204
Interior doors	3.20	3.00	3.58	3.26	4.07	3.45	0.514
Window lineals	3.19	2.69	3.88	2.93	4.29	3.68	**0.035**
RTA Furniture	3.10	3.21	3.78	2.90	4.34	3.60	0.487
Sill plates	3.03	2.70	3.20	3.32	3.69	3.33	0.637
Floor underlayment	2.36	2.71	2.92	2.47	3.07	2.13	**0.079**
Bathroom cabinets	2.35	3.00	2.55	2.22	3.41	2.48	0.009
Kitchen cabinets	2.29	3.00	2.55	2.00	3.38	2.43	**0.003**
Roofing	2.22	2.06	3.20	2.57	2.93	2.54	0.168
Beams/headers	2.10	1.94	2.82	2.12	3.14	2.15	0.662
Roof sheathing	2.03	2.51	2.67	2.35	2.79	1.48	**0.005**
I joists	1.94	1.89	2.73	2.00	3.00	1.90	0.586
Roof trusses	1.82	2.06	2.40	1.94	2.93	1.55	0.338
Wall Framing	1.77	2.03	2.91	2.19	2.62	1.49	**0.004**

Table 114 – Comparison of Ranked Substitution Potential, All Respondents

Of respondents who indicated that their <u>experience</u> with woodfiber-plastic composites is average or above average (3 or greater on a scale of 0 to 5), Deck Railing Systems is mentioned as the building component with the most substitution potential by the total population. This can be seen in the table below followed by tables summarizing responses from each of the separate populations.

Building Component	Total			Mean of All Respondents
	N	Mean	Std. Deviation	
Deck railing systems	68	4.24	1.08	3.88
Deck boards/stair treads	71	4.15	1.09	3.86
Fencing	68	3.87	1.18	3.56
Fascia, soffit, corners	68	3.76	1.32	3.50
Molding	68	3.76	1.12	3.54
Exterior door framing	67	3.73	0.98	3.35
Window lineals	59	3.51	1.43	3.19
Siding	66	3.47	1.43	3.29
Interior doors	65	3.37	1.17	3.20
Sill plates	66	3.33	1.53	3.03
RTA Furniture	52	3.27	1.29	3.10
Roofing	62	2.42	1.44	2.22
Bathroom cabinets	61	2.36	1.54	2.35
Beams/headers	67	2.28	1.77	2.10
Floor underlayment	68	2.28	1.48	2.36
Kitchen cabinets	61	2.26	1.53	2.29
I joists	67	2.06	1.80	1.94
Roof sheathing	68	1.90	1.58	2.03
Roof trusses	68	1.84	1.72	1.82
Wall Framing	66	1.76	1.55	1.77

Table 115 – Ranked Substitution Potential, Experienced Respondents, Total

Building Component	LnO			Mean of All Respondents
	N	Mean	Std. Deviation	
Siding	7	4.86	0.38	3.23
Fascia, soffit, corners	7	4.71	0.49	3.34
Fencing	7	4.43	0.53	3.46
Exterior door framing	7	4.29	1.11	2.74
Kitchen cabinets	7	4.29	0.49	3.00
Bathroom cabinets	7	4.29	0.49	3.00
Molding	7	4.29	1.11	3.54
RTA Furniture	7	4.29	0.76	3.21
Interior doors	7	4.14	1.07	3.00
Deck railing systems	7	4.00	0.58	3.35
Sill plates	7	3.83	1.47	2.70
Window lineals	7	3.57	1.72	2.69
Floor underlayment	7	3.43	1.51	2.71
Roofing	7	3.29	0.95	2.06
Roof sheathing	7	3.14	1.35	2.51
Deck boards/stair treads	7	3.14	1.35	3.17
I joists	7	3.00	1.53	1.89
Beams/headers	7	3.00	1.53	1.94
Roof trusses	7	3.00	1.63	2.06
Wall Framing	7	2.86	1.21	2.03

Table 116 – Ranked Substitution Potential, Experienced Respondents, LnO

Building Component	Prime Contractors			Mean of All Respondents
	N	Mean	Std. Deviation	
Window lineals	3	4.00	0.00	3.88
Molding	4	4.00	0.82	3.42
Interior doors	5	3.80	0.45	3.58
Fascia, soffit, corners	5	3.75	0.50	4.00
Fencing	4	3.75	1.26	3.83
Exterior door framing	5	3.60	0.89	3.27
Siding	5	3.60	1.14	3.58
Beams/headers	4	3.50	1.00	2.82
Sill plates	4	3.50	1.29	3.20
Deck railing systems	3	3.33	0.58	3.82
RTA Furniture	5	3.33	0.58	3.78
I joists	4	3.25	0.96	2.73
Wall Framing	5	3.20	1.30	2.91
Roofing	5	3.20	0.84	3.20
Deck boards/stair treads	4	3.00	0.82	3.69
Floor underlayment	5	2.80	0.84	2.92
Roof trusses	5	2.60	1.14	2.40
Roof sheathing	5	2.60	1.34	2.67
Kitchen cabinets	5	2.60	1.14	2.55
Bathroom cabinets	5	2.60	1.14	2.55

Table 117 – Ranked Substitution Potential, Experienced Respondents, Prime Contractors

Building Component	"Top 200+"			Mean of All Respondents
	N	Mean	Std. Deviation	
Deck boards/stair treads	8	4.38	0.74	3.90
Deck railing systems	8	4.38	0.74	3.85
Fencing	7	4.14	0.69	3.71
Fascia, soffit, corners	8	4.13	0.83	3.37
Exterior door framing	8	4.00	0.93	3.80
Siding	8	3.88	0.99	3.63
Sill plates	8	3.63	1.69	3.32
Molding	8	3.50	1.41	3.53
Interior doors	8	3.00	0.93	3.26
RTA Furniture	5	2.80	1.10	2.90
Window lineals	4	2.75	1.71	2.93
Roofing	6	2.67	1.51	2.57
Floor underlayment	8	2.50	1.41	2.47
Bathroom cabinets	8	2.50	1.20	2.22
Beams/headers	7	2.14	1.68	2.12
Roof sheathing	7	2.14	1.57	2.35
Kitchen cabinets	8	2.13	1.36	2.00
Wall Framing	7	2.00	2.00	2.19
Roof trusses	7	2.00	2.08	1.94
I joists	7	1.71	1.70	2.00

Table 118 – Ranked Substitution Potential, Experienced Respondents, "Top 200+"

Building Component	Wholesalers			Mean of All Respondents
	N	Mean	Std. Deviation	
Deck railing systems	18	4.17	1.38	3.96
Deck boards/stair treads	19	4.11	1.15	4.07
Fencing	18	3.94	1.43	3.69
Molding	16	3.94	1.00	4.36
Window lineals	17	3.82	1.13	4.29
Exterior door framing	17	3.71	0.99	4.11
Interior doors	17	3.59	1.12	4.07
Sill plates	18	3.33	1.50	3.69
RTA Furniture	12	3.25	1.14	4.34
Fascia, soffit, corners	17	3.24	1.95	3.86
Siding	15	2.60	1.84	3.19
Floor underlayment	17	2.35	1.77	3.07
Bathroom cabinets	15	2.20	1.61	3.41
Roofing	17	2.18	1.51	2.93
Kitchen cabinets	15	2.13	1.55	3.38
Beams/headers	17	2.12	1.73	3.14
Roof sheathing	17	2.06	1.85	2.79
I joists	17	2.00	1.73	3.00
Roof trusses	17	1.82	1.78	2.93
Wall Framing	17	1.65	1.41	2.62

Table 119 – Ranked Substitution Potential, Experienced Respondents, Wholesalers

Building Component	Retailers			Mean of All Respondents
	N	Mean	Std. Deviation	
Deck boards/stair treads	33	4.48	0.91	4.40
Deck railing systems	32	4.38	1.07	4.38
Fascia, soffit, corners	32	3.75	1.08	3.78
Fencing	32	3.66	1.21	3.73
Molding	33	3.61	1.14	3.43
Exterior door framing	30	3.57	0.97	3.75
Siding	31	3.45	1.23	3.58
Window lineals	28	3.36	1.57	3.68
Sill plates	30	3.13	1.61	3.33
RTA Furniture	25	3.08	1.47	3.60
Interior doors	28	3.07	1.27	3.45
Roofing	27	2.15	1.51	2.54
Beams/headers	32	2.09	1.92	2.15
Bathroom cabinets	26	1.85	1.49	2.48
Floor underlayment	31	1.84	1.29	2.13
I joists	32	1.81	1.94	1.90
Kitchen cabinets	26	1.77	1.42	2.43
Roof trusses	32	1.44	1.63	1.55
Roof sheathing	32	1.38	1.34	1.48
Wall Framing	30	1.27	1.41	1.49

Table 120 – Ranked Substitution Potential, Experienced Respondents, Retailers

When comparing the substitution ratings for woodfiber-plastic composites for various building components between the respondents who said they had experience with woodfiber-plastic composites from each population it is seen that their perceptions are statistically significantly different based on a 0.10 significance level using ANOVA for the following building components: Deck Boards/Stair Treads, Siding, Bathroom Cabinets, Floor Underlayment, Kitchen Cabinets, Roof Sheathing, and Wall Framing. This is summarized in the table below.

Building Component	Total	LnO	Prime	"Top 200"	Wholesalers	Retailers	Sig.
Deck railing systems	4.24	4.00	3.33	4.38	4.17	4.38	0.542
Deck boards/stair treads	4.15	3.14	3.00	4.38	4.11	4.48	**0.005**
Fencing	3.87	4.43	3.75	4.14	3.94	3.66	0.555
Fascia, soffit, corners	3.76	4.71	3.75	4.13	3.24	3.75	0.133
Molding	3.76	4.29	4.00	3.50	3.94	3.61	0.540
Exterior door framing	3.73	4.29	3.60	4.00	3.71	3.57	0.443
Window lineals	3.51	3.57	4.00	2.75	3.82	3.36	0.636
Siding	3.47	4.86	3.60	3.88	2.60	3.45	**0.008**
Interior doors	3.37	4.14	3.80	3.00	3.59	3.07	0.134
Sill plates	3.33	3.83	3.50	3.63	3.33	3.13	0.838
RTA Furniture	3.27	4.29	3.33	2.80	3.25	3.08	0.233
Roofing	2.42	3.29	3.20	2.67	2.18	2.15	0.233
Bathroom cabinets	2.36	4.29	2.60	2.50	2.20	1.85	**0.004**
Beams/headers	2.28	3.00	3.50	2.14	2.12	2.09	0.475
Floor underlayment	2.28	3.43	2.80	2.50	2.35	1.84	**0.096**
Kitchen cabinets	2.26	4.29	2.60	2.13	2.13	1.77	**0.002**
I joists	2.06	3.00	3.25	1.71	2.00	1.81	0.344
Roof sheathing	1.90	3.14	2.60	2.14	2.06	1.38	**0.050**
Roof trusses	1.84	3.00	2.60	2.00	1.82	1.44	0.199
Wall Framing	1.76	2.86	3.20	2.00	1.65	1.27	**0.020**

Table 121 – Comparison of Ranked Substitution Potential, Experienced Respondents

Of respondents who indicated that their knowledge of woodfiber-plastic composites is average or above average (3 or greater on a scale of 0 to 5), Deck Railing Systmes is mentioned as the building component with the most substitution potential, followed by Deck Boards/Stair Treads by the combined population. This can be seen in the following table of the total population followed by tables for each individual population.

Building Component	Total			Mean of All Respondents
	N	Mean	Std. Deviation	
Deck railing systems	90	4.10	1.20	3.88
Deck boards/stair treads	93	4.06	1.20	3.86
Fencing	89	3.78	1.29	3.56
Molding	87	3.68	1.12	3.54
Fascia, soffit, corners	88	3.60	1.35	3.50
Exterior door framing	87	3.57	1.04	3.35
Window lineals	78	3.38	1.37	3.19
Siding	86	3.38	1.37	3.29
Interior doors	84	3.29	1.18	3.20
Sill plates	86	3.20	1.49	3.03
RTA Furniture	67	3.19	1.27	3.10
Floor underlayment	87	2.37	1.46	2.36
Roofing	79	2.37	1.41	2.22
Bathroom cabinets	78	2.31	1.47	2.35
Kitchen cabinets	78	2.23	1.46	2.29
Beams/headers	85	2.18	1.69	2.10
I joists	85	2.02	1.73	1.94
Roof sheathing	86	1.91	1.50	2.03
Roof trusses	86	1.86	1.65	1.82
Wall Framing	84	1.83	1.50	1.77

Table 122 – Ranked Substitution Potential, Knowledgeable Respondents, Total

Building Component	LnO			Mean of All Respondents
	N	Mean	Std. Deviation	
Molding	13	4.08	1.12	3.54
Fencing	13	4.00	1.29	3.46
Siding	13	3.92	1.44	3.23
Fascia, soffit, corners	13	3.92	1.32	3.34
RTA Furniture	12	3.83	0.94	3.21
Kitchen cabinets	13	3.77	0.93	3.00
Bathroom cabinets	13	3.77	0.93	3.00
Deck railing systems	13	3.62	1.39	3.35
Floor underlayment	13	3.38	1.33	2.71
Exterior door framing	13	3.31	1.44	2.74
Sill plates	13	3.31	1.49	2.70
Interior doors	13	3.23	1.30	3.00
Window lineals	13	3.23	1.48	2.69
Deck boards/stair treads	13	3.23	1.64	3.17
Roof sheathing	13	2.92	1.50	2.51
Wall Framing	13	2.77	1.42	2.03
Roofing	13	2.69	1.44	2.06
Roof trusses	13	2.62	1.71	2.06
Beams/headers	13	2.38	1.61	1.94
I joists	13	2.31	1.84	1.89

Table 123 – Ranked Substitution Potential, Knowledgeable Respondents, LnO

Building Component	Prime Contractors			Mean of All Respondents
	N	Mean	Std. Deviation	
Window lineals	5	4.00	0.00	3.88
Fencing	6	4.00	1.10	3.83
Interior doors	7	3.86	0.38	3.58
Fascia, soffit, corners	6	3.83	0.41	4.00
Deck railing systems	5	3.80	0.84	3.82
Siding	7	3.71	0.95	3.58
RTA Furniture	5	3.60	0.55	3.78
Deck boards/stair treads	6	3.50	1.05	3.69
Molding	6	3.50	1.05	3.42
Exterior door framing	7	3.43	0.98	3.27
Sill plates	6	3.17	1.17	3.20
Roofing	7	3.14	0.90	3.20
Beams/headers	6	3.00	1.10	2.82
Wall Framing	7	2.86	1.21	2.91
I joists	6	2.83	0.98	2.73
Floor underlayment	7	2.71	0.76	2.92
Kitchen cabinets	6	2.50	1.05	2.55
Bathroom cabinets	6	2.50	1.05	2.55
Roof trusses	7	2.43	0.98	2.40
Roof sheathing	7	2.43	1.13	2.67

Table 124 – Ranked Substitution Potential, Knowledgeable Respondents, Prime Contractors

Building Component	"Top 200+"			Mean of All Respondents
	N	Mean	Std. Deviation	
Deck boards/stair treads	15	4.07	1.28	3.90
Deck railing systems	15	3.93	1.28	3.85
Exterior door framing	15	3.80	1.08	3.80
Fencing	14	3.71	1.38	3.71
Siding	14	3.64	0.93	3.63
Fascia, soffit, corners	14	3.57	1.34	3.37
Molding	14	3.50	1.22	3.53
Sill plates	14	3.36	1.50	3.32
Interior doors	14	3.14	0.95	3.26
Window lineals	10	2.80	1.48	2.93
RTA Furniture	8	2.63	0.92	2.90
Roofing	10	2.50	1.35	2.57
Floor underlayment	14	2.43	1.22	2.47
Bathroom cabinets	13	2.23	1.24	2.22
Wall Framing	12	2.08	1.68	2.19
Roof sheathing	12	2.08	1.24	2.35
Kitchen cabinets	13	2.00	1.29	2.00
Roof trusses	12	1.92	1.62	1.94
I joists	12	1.83	1.47	2.00
Beams/headers	12	1.75	1.42	2.12

Table 125 – Ranked Substitution Potential, Knowledgeable Respondents, "Top 200+"

Building Component	Wholesalers			Mean of All Respondents
	N	Mean	Std. Deviation	
Deck railing systems	20	4.20	1.32	3.96
Deck boards/stair treads	21	4.14	1.11	4.07
Molding	16	3.94	1.00	4.36
Fencing	19	3.84	1.46	3.69
Window lineals	17	3.82	1.13	4.29
Exterior door framing	17	3.71	0.99	4.11
Interior doors	17	3.59	1.12	4.07
Sill plates	18	3.33	1.50	3.69
RTA Furniture	12	3.25	1.14	4.34
Fascia, soffit, corners	18	3.17	1.92	3.86
Siding	16	2.56	1.79	3.19
Floor underlayment	17	2.35	1.77	3.07
Bathroom cabinets	15	2.20	1.61	3.41
Roofing	17	2.18	1.51	2.93
Kitchen cabinets	15	2.13	1.55	3.38
Beams/headers	17	2.12	1.73	3.14
Roof sheathing	17	2.06	1.85	2.79
I joists	17	2.00	1.73	3.00
Roof trusses	17	1.82	1.78	2.93
Wall Framing	17	1.65	1.41	2.62

Table 126 – Ranked Substitution Potential, Knowledgeable Respondents, Wholesalers

Building Component	Retailers			Mean of All Respondents
	N	Mean	Std. Deviation	
Deck boards/stair treads	38	4.39	0.92	4.40
Deck railing systems	37	4.32	1.06	4.38
Fascia, soffit, corners	37	3.68	1.13	3.78
Fencing	37	3.65	1.25	3.73
Exterior door framing	35	3.54	0.92	3.75
Molding	38	3.53	1.13	3.43
Siding	36	3.39	1.25	3.58
Window lineals	33	3.30	1.47	3.68
Interior doors	33	3.09	1.33	3.45
Sill plates	35	3.03	1.60	3.33
RTA Furniture	30	3.00	1.51	3.60
Beams/headers	37	2.14	1.87	2.15
Roofing	32	2.13	1.43	2.54
Floor underlayment	36	1.92	1.38	2.13
I joists	37	1.86	1.89	1.90
Bathroom cabinets	31	1.74	1.39	2.48
Kitchen cabinets	31	1.68	1.33	2.43
Roof trusses	37	1.49	1.63	1.55
Roof sheathing	37	1.32	1.25	1.48
Wall Framing	35	1.29	1.32	1.49

Table 127 – Ranked Substitution Potential, Knowledgeable Respondents, Retailers

When comparing the substitution ratings for woodfiber-plastic composites for various building components between the respondents who said they had knowledge of woodfiber-plastic composites from each population it is seen that their perceptions are statistically significantly different based on a 0.10 significance level using ANOVA for the following building components: Deck Boards/Stair Treads, Siding, Floor Underalyment, Bathroom Cabinets, Kitchen Cabinets, Roof Sheathing, and Wall Framing. This is summarized in the table below.

Building Component	Total	LnO	Prime	"Top 200"	Wholesalers	Retailers	Sig.
Deck railing systems	4.10	3.62	3.80	3.93	4.20	4.32	0.391
Deck boards/stair treads	4.06	3.23	3.50	4.07	4.14	4.39	**0.027**
Fencing	3.78	4.00	4.00	3.71	3.84	3.65	0.913
Molding	3.68	4.08	3.50	3.50	3.94	3.53	0.449
Fascia, soffit, corners	3.60	3.92	3.83	3.57	3.17	3.68	0.585
Exterior door framing	3.57	3.31	3.43	3.80	3.71	3.54	0.745
Window lineals	3.38	3.23	4.00	2.80	3.82	3.30	0.306
Siding	3.38	3.92	3.71	3.64	2.56	3.39	**0.067**
Interior doors	3.29	3.23	3.86	3.14	3.59	3.09	0.426
Sill plates	3.20	3.31	3.17	3.36	3.33	3.03	0.938
RTA Furniture	3.19	3.83	3.60	2.63	3.25	3.00	0.209
Floor underlayment	2.37	3.38	2.71	2.43	2.35	1.92	**0.033**
Roofing	2.37	2.69	3.14	2.50	2.18	2.13	0.390
Bathroom cabinets	2.31	3.77	2.50	2.23	2.20	1.74	**0.001**
Kitchen cabinets	2.23	3.77	2.50	2.00	2.13	1.68	**0.000**
Beams/headers	2.18	2.38	3.00	1.75	2.12	2.14	0.668
I joists	2.02	2.31	2.83	1.83	2.00	1.86	0.723
Roof sheathing	1.91	2.92	2.43	2.08	2.06	1.32	**0.010**
Roof trusses	1.86	2.62	2.43	1.92	1.82	1.49	0.241
Wall Framing	1.83	2.77	2.86	2.08	1.65	1.29	**0.006**

Table 128 – Comparison of Ranked Substitution Potential, Knowledgeable Respondents

Communication Methods

Communication Construct – LNO's, Prime Contractors, "Top 200+" Builders, Wholesalers, & Retailers

Respondents were asked to rate how important (0 different factors were for their company in learning about new building materials. Opinions of Peers (mean = 3.60) was rated as the most critical factor followed by Trade Show Exhibits (mean = 3.38) and Trade/Industry Journals (mean = 3.35) by the total population. This can be seen in table below followed by tables for each individual population.

Total									
	N	0 - No importance	1	2	3	4	5 - critically important	Mean	Std. Dev.
Current Building Material Suppliers*	91	1	1	12	25	37	15	3.55	1.02
Trade show exhibits	140	6	6	17	41	46	24	3.34	1.26
Trade/industry journals	141	2	9	23	47	47	13	3.18	1.11
Opinions of peers	139	16	7	22	35	37	22	2.98	1.52
Customers (homeowners)*	89	5	11	21	18	17	17	2.92	1.49
Ads from material mfgrs	140	5	11	33	58	25	8	2.79	1.12
Conferences/seminars	141	10	19	25	42	31	14	2.76	1.39
Direct mail	140	15	30	35	35	19	6	2.22	1.34
Government research	140	23	38	25	35	11	8	1.98	1.42
Media promotion	140	23	38	38	28	10	3	1.81	1.26
Other - CSI Spec Data Sheets	1						1	5.00	0.00
Other - Professional Publications	1					1		4.00	0.00
Other - Professional Training/Cont. Ed.	1					1		4.00	0.00
Other - Field Observations	1						1	5.00	0.00
Other - Arch. Specs	1						1	5.00	0.00
Other - in Contract	1						1	5.00	0.00
Other - Use Spec. Matl.	1						1	5.00	0.00
Other - Salesman/Distribution	1						1	5.00	0.00
Other - Demonstrations	1						1	5.00	0.00
Other - Sales Calls	1						1	5.00	0.00
Other - Sales Representatives	1						1	5.00	0.00
Other - Professional Contractors	1						1	5.00	0.00

*only on “Top 200” Builders, Wholesalers, & Retailers surveys

Table 129 – Communications Channel Importance Ranking, Total

LnO									
	N	0 - No importance	1	2	3	4	5 - critically important	Mean	Std. Dev.
Opinions of peers	37	1		1	8	15	12	3.95	1.05
Conferences/seminars	37		1	3	6	16	11	3.89	1.02
Trade show exhibits	37			5	13	11	8	3.59	0.98
Trade/industry journals	37		2	3	12	14	6	3.51	1.04
Ads from material mfgrs	37		3	6	10	12	6	3.32	1.18
Government research	37	1	4	3	13	9	7	3.24	1.32
Direct mail	36	3	5	7	11	6	4	2.67	1.43
Media promotion	36	3	5	5	16	5	2	2.58	1.30
Other - CSI Spec Data Sheets	1						1	5.00	0.00
Other - Field Observations	1						1	5.00	0.00
Other - Professional Publications	1					1		4.00	0.00
Other - Professional Training/Cont. Ed.	1					1		4.00	0.00

Table 130 – Communications Channel Importance Ranking, LnO

Prime Contractors									
	N	**0 - No importance**	**1**	**2**	**3**	**4**	**5 - critically important**	**Mean**	**Std. Dev.**
Trade/industry journals	13		1	1	5	5	1	3.31	1.03
Opinions of peers	13	2		2	1	6	2	3.15	1.68
Ads from material mfgrs	13	1		4	7		1	2.62	1.12
Conferences/seminars	13	1	2	2	7	1		2.38	1.12
Trade show exhibits	13	2	2	1	5	3		2.38	1.45
Government research	13	1	2	5	3	1	1	2.31	1.32
Direct mail	13	2	1	5	3	1	1	2.23	1.42
Media promotion	13	2	4	5	2			1.54	0.97
Other - Arch. Specs	1						1	5.00	0.00
Other - in Contract	1						1	5.00	0.00
Other - Use Spec. Matl.	1						1	5.00	0.00

Table 131– Communications Channel Importance Ranking, Prime Contractors

"Top 200+"									
	N	**0 - No importance**	**1**	**2**	**3**	**4**	**5 - critically important**	**Mean**	**Std. Dev.**
Current Building Material Suppliers	22			1	5	8	8	4.05	0.90
Trade show exhibits	22		1	3	5	8	5	3.59	1.14
Opinions of peers	22			5	8	7	2	3.27	0.94
Trade/industry journals	22		3	2	8	8	1	3.09	1.11
Ads from material mfgrs	22			7	10	4	1	2.95	0.84
Customers (homeowners)	22	1	3	5	4	5	4	2.95	1.50
Conferences/seminars	22	1	4	3	9	3	2	2.68	1.32
Direct mail	22		7	2	7	6		2.55	1.22
Government research	22	2	8	5	7			1.77	1.02
Media promotion	22	3	8	7	2	1	1	1.68	1.25
Other - Salesman/Distribution	1						1	5.00	0.00

Table 132 – Communications Channel Importance Ranking, "Top 200+"

Wholesalers									
	N	**0 - No importance**	**1**	**2**	**3**	**4**	**5 - critically important**	**Mean**	**Std. Dev.**
Current Building Material Suppliers	29		1	6	7	10	5	3.41	1.12
Trade/industry journals	29		3	5	8	10	3	3.17	1.17
Trade show exhibits	28	2	1	5	8	7	5	3.14	1.41
Customers (homeowners)	28	4	5	4	6	3	6	2.61	1.75
Ads from material mfgrs	29	2	2	7	13	5		2.59	1.09
Conferences/seminars	29	2	5	12	6	4		2.17	1.10
Opinions of peers	28	7	3	8	6	2	2	1.96	1.53
Direct mail	29	3	9	7	7	3		1.93	1.19
Media promotion	29	8	10	7	3	1		1.28	1.10
Government research	28	9	11	4	4			1.11	1.03
Other - Demonstrations	1						1	5.00	0.00
Other - Sales Calls	1						1	5.00	0.00
Other - Sales Representatives	1						1	5.00	0.00
Other - Professional Contractors	1						1	5.00	0.00

Table 133 – Communications Channel Importance Ranking, Wholesalers

Retailers									
	N	**0 - No importance**	**1**	**2**	**3**	**4**	**5 - critically important**	**Mean**	**Std. Dev.**
Trade show exhibits	40	2	2	3	10	17	6	3.40	1.28
Current Building Material Suppliers	40	1		5	13	19	2	3.38	0.95
Customers (homeowners)	39		3	12	8	9	7	3.13	1.26
Trade/industry journals	40	2		12	14	10	2	2.90	1.10
Opinions of peers	39	6	4	6	12	7	4	2.56	1.55
Ads from material mfgrs	39	2	6	9	18	4		2.41	1.04
Conferences/seminars	40	6	7	5	14	7	1	2.30	1.42
Direct mail	40	7	8	14	7	3	1	1.85	1.27
Media promotion	40	7	11	14	5	3		1.65	1.14
Government research	40	10	13	8	8	1		1.43	1.15

Table 134 – Communications Channel Importance Ranking, Retailers

When comparing the importance of communication factors for respondents companies in learning about new building materials between the individual populations it is seen that their perceptions are statistically significantly different based on a 0.10 significance level using ANOVA for the following factors: Conferences/Seminars, Government Research, Ads from Material Manufacturers, Trade Show Exhibits, Direct Mail, Media Promotion, Opinions of Peers, and Current Building Material Suppliers.

Communications Channel	**Total**	**LnO**	**Prime**	**"Top 200+"**	**Wholesalers**	**Retailers**	**Sig.**
Current Building Material Suppliers	3.55	—	—	4.05	3.41	3.38	**0.031**
Trade show exhibits	3.34	3.59	2.38	3.59	3.14	3.40	**0.029**
Trade/industry journals	3.18	3.51	3.31	3.09	3.17	2.90	0.181
Opinions of peers	2.98	3.95	3.15	3.27	1.96	2.56	**0.000**
Customers (homeowners)	2.92	—	—	2.95	2.61	3.13	0.369
Ads from material mfgrs	2.79	3.32	2.62	2.95	2.59	2.41	**0.004**
Conferences/seminars	2.76	3.89	2.38	2.68	2.17	2.30	**0.000**
Direct mail	2.22	2.67	2.23	2.55	1.93	1.85	**0.042**
Government research	1.98	3.24	2.31	1.77	1.11	1.43	**0.000**
Media promotion	1.81	2.58	1.54	1.68	1.28	1.65	**0.000**

Table 135 – Comparison of Communications Channel Importance Ranking

Additionally, the importance of communications factors was looked at by region and job title for the LnO population as seen in the following tables.

	South		Southwest		Pacific/Northwest		Atlantic/Northeast		Total	
	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N
Opinions of peers	3.78	9	4.00	14	3.33	6	4.50	8	3.95	37
Conferences/seminars	3.56	9	4.00	14	4.00	6	4.00	8	3.89	37
Trade show exhibits	3.00	9	3.71	14	4.00	6	3.75	8	3.59	37
Trade/industry journals	3.00	9	3.64	14	3.50	6	3.88	8	3.51	37
Ads from material mfgrs	2.56	9	3.71	14	3.33	6	3.50	8	3.32	37
Government research	3.44	9	3.07	14	3.50	6	3.13	8	3.24	37
Other	4.50	2			0.00	1			3.00	3
Direct mail	1.67	9	3.00	13	2.83	6	3.13	8	2.67	36
Media promotion	1.44	9	2.85	13	2.67	6	3.38	8	2.58	36

Table 136 – Communications Channel Importance Ranking by Region

	Engineer		Facility Maintenance Supervisor		Architect		Construction Administration		Total	
	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N
Opinions of peers	4.10	10	4.17	6	4.17	12	3.33	9	3.95	37
Conferences/seminars	3.40	10	3.83	6	4.17	12	4.11	9	3.89	37
Trade show exhibits	3.20	10	3.50	6	3.75	12	3.89	9	3.59	37
Trade/industry journals	3.40	10	3.83	6	3.50	12	3.44	9	3.51	37
Ads from material mfgrs	3.20	10	3.17	6	3.42	12	3.44	9	3.32	37
Government research	3.30	10	3.00	6	3.50	12	3.00	9	3.24	37
Other	0.00		0.00		4.50	2	0.00	1	3.00	3
Direct mail	2.44	9	3.17	6	2.42	12	2.89	9	2.67	36
Media promotion	2.78	9	2.67	6	2.33	12	2.67	9	2.58	36

Table 137 – Communications Channel Importance Ranking by Job Title

Opinion of Peers – LNO's, Prime Contractors, "Top 200+" Builders, Wholesalers, & Retailers

If respondents indicated the importance of Opinions of Peers as anything but "0", they were asked to specify whom they considered their peer groups. This can be seen in the following tables, first for builders and then for wholesalers.

Peer Groups	Total Frequency	LnO Frequency	Prime Contractors Frequency	"Top 200+" Frequency
Engineers				
Design n = 3				
Structural n = 1	18	18		
Architects	10	10		
Construction mgrs/contractors	9	4	4	1
Competition/ Other Builders	9			9
Navy and civilian PWDs	3	3		
Project Managers	3	3		
Subcontractors	3		2	1
Facility Maintenance Personnel (e.g., ACOS)	2	2		
Manufacturer's reps	2	2		
Public Works Mgmt	1	1		
Shop personnel	1	1		
Quality Control mgrs	1	1		
Field personnel, ROICCS	1	1		
Trade organization reps	1	1		
Planners	1	1		
Estimators	1	1		
ABC, AGC, SAME, DBIA, etc.	1		1	
ABC, Heavy Construction Ind Assoc.	1		1	
Designers	1		1	
Foreman	1		1	
Managers	1		1	
Others who build military housing	1		1	
Owners	1		1	
Superintendents	1		1	
BSC	1			1
CEO's of other cos.	1			1
EFL	1			1
Local HBA	1			1
Pulte	1			1
Suppliers	1			1
Colony	1			1
Manufacturers	1			1
Retailers	1			1
VP Construction	1			1
Total	**84**	**49**	**14**	**21**

Table 138 – Peer Groups, Builder Populations

Peers	Total Frequency	Wholesalers Frequency	Retailers Frequency
Wholesalers	6	5	1
Buying Group/ Other members of our co-op	4	1	3
Competition	4	1	3
Customers	4	2	2
Dealers	4		4
Management	4	1	3
Builders	3	2	1
Fellow Workers	3	1	2
Lumber Yards	3		3
Manufacturers	3	2	1
Buyers	2		2
Home Builders Associations (local and national)	2	1	1
Lumber Dealers	2	2	
Outside sales representatives / sales group	2		2
Retailers	2		2
Vendors	2	1	1
Architects	1	1	
Building Material Wholesalers	1	1	
Building Materials Associations	1		1
Buyer's Customers	1		1
Developers	1	1	
Friends in the Industry	1	1	
Home Depot	1	1	
Independent Lumber Companies	1		1
Major Suppliers	1	1	
Members of ENAP	1		1
Mills and Producers	1		1
NRLA	1		1
NSDJA	1	1	
Other Home Centers	1		1
Roundtable Group	1		1
Yard Managers	1		1
Total	**66**	**26**	**40**

Table 139 – Peer Groups, Wholesaler Populations

Trade or Professional Associations – LNO's, Prime Contractors, & "Top 200+" Builders

Respondents were asked to indicate the number of trade or professional associations with which they held membership. Twenty-eight percent (19/67 = 28.36%) of the total population held no memberships with any trade or professional organizations while ten percent (7/67 = 10.45%) were members of five or more associations. Counts for each individual population can be seen below and in Figure 28.

# of Memberships	Total	LnO	Prime Contractors	“Top 200+”
0	19	17	2	
1	17	9	2	6
2	14	5	3	6
3	9	5	1	3
4	1		1	
5 or more	7		3	4
Total	67	36	12	19

Table 140 – Number of Memberships in Professional Associations

Respondents were asked to list the associations that they are member of. This can be seen in the following table.

Professional/Trade Association	Total Frequency	LnO Frequency	Prime Contractors Frequency	"Top 200+" Frequency
SAME - Society of American Military Engineers	11	8	3	
NAHB	11			11
AIA – American Institute of Architects	7	4	2	1
NSPE - National Society of Professional Engineers	6	4	2	
ASCE - American Society of Civil Engineers	5	5		
CSI – Construction Specifications Institute	3	3		
ASME – American Society of Mechanical Engineers	3	1	2	
American General Contractor's Assoc.	3		3	
National Council of Arch. Reg. Board	2	2		
ACI - American Concrete Institute	2	1	1	
VA Homebuilders	2		2	
GAHB	2			2
Building Systems Council	2			2
ASHRAE - American Society of Heating, Refrigerating, and Air-Conditioning Engineers	1	1		
AWWA – American Water Works Association	1	1		
CA Architect Lic.	1	1		
Filipino American League of Architects and Engineers	1	1		
SEAOC - Structural Engineering Assoc. of CA	1	1		
Wastewater Environment Federation	1	1		
ABC	1		1	
AEG	1		1	
BEAVERS	1		1	
DBIA	1		1	
JAME	1		1	
NIBS	1		1	
SAE – Society of American Engineers	1		1	
Blue Book	1		1	
CA Building Ind. Assn.	1			1
HBA	1			1
Indiana Mobile Home Assn.	1			1
MD Home Builders	1			1
Metro Atlanta Homebuilders Assn.	1			1
Mid Atl. Bldg. Sys. Council	1			1
Southern Nevada Home Builders	1			1
MHI	1			1
NAPM	1			1
Nat'l Mfg. Housing Assn.	1			1
NCOSH	1			1
WIC - Women in Construction	1			1
Building Trades Assn.	1			1
Hickory Consortium	1			1
ICBO	1			1
Northeast Building Systems Council	1			1
BAGT (Bldrs. Assn. Of Greater Tampa)	1			1
Total	**90**	**34**	**23**	**33**

Table 141 – Professional Association Memberships

Trade Shows – LNO's, Prime Contractors, "Top 200+" Builders, Wholesalers, & Retailers

Respondents from the LnO and Prime Contractors populations were asked to indicate the number of trade shows that their organization attended in 2000 and 2001. Thirty-eight percent (18/48 = 37.5%) of respondent's organizations did not attend trade shows in 2000

and 2001 while ten percent (5/48 = 10.42%) attended five or more trade shows. This can be seen in the following table and in Figure 29.

# of Trade Shows	Total	LnO	Prime Contractors
0	18	13	5
1	11	10	1
2	7	5	2
3	5	4	1
4	2		2
5 or more	5	3	2
Total	48	35	13

Table 142 – Number of Trade Shows Attended

All respondents were asked to list trade shows that their organizations attended. This can be seen below first for the three builder populations and then for the Wholesalers and Retailers populations.

Conference/Seminar Name	Total Frequency	LnO Frequency	Prime Contractors Frequency	"Top 200+" Frequency
CSI: (Construction Specifications Institute)				
CSI Exposition / Trade show n = 4				
CSI/AIA Product Show n = 2				
CSI Local Meeting n = 1	7	7		
Builder's/Construction show	6	5	1	
International Builders Show	4			4
AIA - American Institute of Architects	3	1	2	
World of Concrete	3		1	2
National Builders Show	3			3
Local Builders Show	3			3
NAHB	3			3
Home Builders	2	2		
Roofing Trade Show/Seminars	2	2		
AGC Contractors trade show (Assoc. General Contractors of America)	1	1		
ASCE Design of Metal Bldg systems	1	1		
ASHE – American Society of Highway Engineers	1	1		
Asphalt seminar	1	1		
Concrete	1	1		
Home Remodelers	1	1		
Jackson City Industrial Trade Show	1	1		
Local home & garden show	1	1		
Masonry	1	1		
MetalCon	1	1		
NEOCON 2002 World Trade Fair	1	1		
Parade of Homes - GCA	1	1		
Steel	1	1		
ConExpo	1		1	
FED COM	1		1	
NSPE	1		1	
Tidewater VA Home Builders	1		1	
VA Engineering Conference	1		1	
VA Home Builders	1		1	
SEBC	1			1
PCBC	1			1
BCC	1			1
Regional Manufactured Housing Show	1			1
Midwest Mfg. Housing L'ville, KY Show	1			1
MD Home Builders	1			1
Coverings	1			1
KBIS	1			1
Total	**63**	**30**	**10**	**23**

Table 143 – Trade Shows Attended, Builder Populations

Trade Show	Total Frequency	Wholesalers Frequency	Retailers Frequency
NAHB	12	4	8
BMA	7	1	6
NAWLA	7	7	
LMC	6		6
NRLA	6	1	5
ENAP	4		4
Hardware Show	4		4
Journal of Light Construction (JLC)	4	1	3
NSDJA	4	3	1
Builders Show	3		3
Co-op Shows	3		3
LAT	3		3
National Hardware Show	3	1	2
National Sash and Door Jobbers Association	3	2	1
Pacific Coast Building Conference (PCBC)	3	1	2
CLA	2	1	1
Fencetech	2		2
Home Builders Show	2	2	
IBS	2	1	1
Orgill Show	2		2
SLMA	2	2	
Southern Building Material Association	2		2
Any state's retail dealer shows	1	1	
AWCI	1	1	
BCMC	1		1
Build Boston	1		1
Building Contractors Assoc.	1	1	
Building Material Wholesalers	1	1	
Buying Co-op Shows	1		1
Buying Group	1		1
Buying Shows - DIB Corp.	1		1
Chicago	1	1	
Chicago Rfg. Contractor Assoc. (CRCA)	1	1	
CISCA	1	1	
CLMA	1	1	
Concrete Show	1		1
Do It Best	1		1
Facilities Management	1		1
FBMA	1		1
Florida Building Material Dealers	1		1
Home Show	1	1	
Hoo Hoo Lumber Fraternity	1	1	
IBSA INC., SmithField. NC	1	1	
ILMDA Show	1		1
International Home Builders	1		1
International Woodworking Fair	1	1	
Kitchen Bath	1		1
Louisville RV Show	1	1	
LWE	1		1
Manufactured Housing Trade Shows	1	1	
MBMDA	1	1	
MERLA?	1	1	
Midwest Rfg. Contractor Assoc. (MRCA)	1	1	
MLMA	1	1	
MW Lumberman's	1		1
N.R.L.A.	1		1
NAFGD	1	1	

Trade Show	Total Frequency	Wholesalers Frequency	Retailers Frequency
NAMDA	1	1	
NASJA	1		1
National Rfg. Contractor Assoc. (NRCA)	1	1	
National Sash & Door	1	1	
National Wood Flooring Assoc.	1	1	
NHRB	1		1
NJ Lumbermans	1		1
NM Lumbermans Show	1		1
Northeast Retailer	1		1
Northwest Lumber Association	1		1
NRCA	1	1	
NWLA	1	1	
Prime Source	1		1
Remodelers Show	1		1
Surfaces	1	1	
Their all the Same	1		1
Various Wholesalers Show	1		1
WWPA	1	1	
Yard & Garden	1		1
Total	**140**	**54**	**86**

Table 144 – Trade Shows Attended, Wholesaler Populations

Conferences/Seminars – LNO's & Prime Contractors

Respondents from the LnO and Prime Contractors populations were asked to indicate the number of conferences/seminars related to building materials they attended in 2000 and 2001. Fifty-six percent (28/50 = 56.0%) of respondents did not attend any seminars in 2000/2001 while only six percent (3/50 = 6.0%) attended fiver or more. See Figure 30.

# of Seminars	Total	LnO	Prime Contractors
0	28	22	6
1	8	5	3
2	5	3	2
3	6	5	1
4	0	0	0
5 or more	3	2	1
Total	50	37	13

Table 145 – Number of Seminars Attended

Respondents were asked to list the building material conferences/seminars that they attended in 2000/2001. This can be seen in the following table.

Conference/Seminar Name	Total Frequency	LnO Frequency	Prime Contractors Frequency
Finish/architectural hardware	3	3	
Concrete Design & Construction	2	2	
CSI Product Fair - Construction Specifications Institute	2	2	
Direct Digital Controls	2	2	
Masonry Design, Brick & Mortar seminar	2	2	
Roofing design	2	2	
AIA - American Institute of Architects	2	2	
AISC Steel Design (American Institute of Steel Construction)	1	1	
Army Corps of Engineers Symposium	1	1	
ASHE – American Society of Highway Engineers	1	1	
ASTEC Acrylic/ceramic coating	1	1	
Beams and lintels	1	1	
Blast Resistant Window	1	1	
Builder/Construction show	1	1	
Composite wall framing	1	1	
Concrete Industry Producers Seminar	1	1	
LEEP Intro seminar	1	1	
Lightweight Concrete	1	1	
Metal con	1	1	
National Hurricane Conference	1	1	
PCI Concrete Properties	1	1	
steel truss framing	1	1	
Waterfront Material trade show	1	1	
Wood Grades	1	1	
Truss Joist, Engineered Beams	1		1
Building Insulation (mold resistant)	1		1
Tidewater VA Homebuilders	1		1
VA Homebuilders	1		1
ConExpo	1		1
VA Engineering conference	1		1
NJPE	1		1
Total	**39**	**32**	**7**

Table 146 – Seminars Attended

Trade/Industry Journals – Prime Contractors, "Top 200+" Builders, Wholesalers, & Retailers

Respondents from the Prime Contractors population were asked to indicate how many trade/industry journals they read on a regular basis. Forty-three percent (6/14 = 42.85%) read five or more journals on a daily basis while only seven percent (1/15 = 7.14%) do not read journals. See Figure 31.

Respondents from the Prime Contractor, "Top 200+" Builders, Wholesalers, and Retailers were asked to specify which journals they read. The first table is responses by the builder populations and the second table lists responses of the wholesaler and retailer populations.

Trade/Industry Journal Name	Total Frequency	Prime Contractors Frequency	“Top 200+” Frequency
Builder Magazine	8		8
Engineering News Record	4	4	
Professional Builder	2	2	8
Journal of Light Construction	2		2
Custom Homes	2		2
Architectural Digest	1	1	
Architectural Record	1	1	
Building Construction & Design	1	1	1
Building Systems	1	1	2
California Builder/Contractors	1	1	
Concrete Products	1	1	
Construction Digest	1	1	
Construction Journal	1	1	
Construction Magazine	1	1	
Consulting Specifier	1	1	
Cro??s	1	1	
Engineering Journal	1	1	
Equipment World	1	1	
Fire Protection Magazine	1	1	
HVAC Magazine	1	1	
Masonry Construction	1	1	
Mechanical Contracting	1	1	
Metal Roof Journal	1	1	
NFPA	1	1	
Power Magazine	1	1	
Professional Remodler	1	1	
Random Lengths	1	1	
Roads & Bridges	1	1	
Concrete Homes	1		1
Home Builder	1		1
Automated Builder	1		1
Business Press	1		1
Big Builder	1		1
Metal Housing	1		1
Tech Home Builder	1		1
Fine Homebuilding	1		1
Total	**49**	**29**	**31**

Table 147 – Trade Journals Read, Builder Populations

Journal	Total Frequency	Wholesalers Frequency	Retailers Frequency
Pro Sales	21	7	14
Home Center News	12	2	10
Home Channel News	6	3	3
Journal of Light Construction	6	2	4
Shelter	5	4	1
Builder	4	1	3
Building Materials Retailer	3	1	2
Building Product Digest	3	1	2
Fenestration	3	1	2
Merchant Magazine	3	1	2
Pro Dealers	3		3
Random Lengths	3		3
Building Materials Dealer	2		2
Construction Dimensions	2	2	
Home Builder	2	1	1
Jobsite	2	1	1
Remodeling News	2	1	1
Builder and Developer	1		1
Builder Material Dealer	1	1	
Builder/Architect	1	1	
Builders Building Systems	1	1	
Builders Digest	1	1	
Building	1		1
Building Systems Magazines	1	1	
Construction Distribution	1		1
Crows Forest Industry Journal	1	1	
Dealer	1		1
Dealer Digest	1		1
Dealer Magazine	1		1
Do It Yourself Retailing	1	1	
DWM	1	1	
FCM	1	1	
Floor Covering Weekly	1	1	
Fogus	1	1	
Form and Function	1	1	
Home Builders/Remodelers Show	1		1
lbm Daily	1		1
LMC	1		1
Lumber Merchant	1	1	
Mobile Home Manufacturer	1	1	
Modern Woodworking	1		1
NABMO	1		1
NAHB	1		1
Nat. Floor Trends	1	1	
NLBMDA Publications	1		1
Paint and Decorating Retailer	1	1	
Pro and Builder Magazines	1		1
Professional Roofing	1	1	
Remodeler Journal	1		1
Retailing	1		1
Roofing Contractor	1	1	
RSI	1	1	
Shelter Building Material Dealer	1	1	
Southern Lumberman	1	1	
Surfaces - Las Vegas	1		1
Sweets	1	1	

Journal	Total Frequency	Wholesalers Frequency	Retailers Frequency
The Paint Dealer	1	1	
Their all the same	1		1
Timber Processing	1	1	
Tools	1		1
Window and Door	1	1	
Wood Digest	1	1	
World Fence News	1		1
Total	**128**	**54**	**74**

Table 148 – Trade Journals Read, Wholesaler and retailer populations

Adoption of New Building Materials

Perceived Benefits of Adopting New Building Materials – LNO's, Prime Contractors, "Top 200+" Builders, Wholesalers, & Retailers

Respondents were asked to rate the importance of a series of perceived benefits of adopting new building materials on a scale of 0 to 5 (0 = No Importance to 5 = Critically Important). Affordability was ranked by the total population as the most important benefit of adoption of new building materials. Durability and Safety were ranked second and third respectively as illustrated in the table below.

Total									
Perceived Benefit	**N**	**No importance**	**1**	**2**	**3**	**4**	**5 - critically important**	**Mean**	**Std. Dev.**
Durability	73			2	7	25	39	4.38	0.78
Safety (reduced risk)	73	1	3	1	14	21	33	4.05	1.14
Affordability	73			4	17	27	25	4.00	0.90
Reduced liability	72	1	3	4	16	20	28	3.88	1.20
Ease of installation	73		1	6	15	32	19	3.85	0.95
Aesthetics	73		1	3	24	30	15	3.75	0.88
Environmentally friendly	73	2	4	6	24	25	12	3.40	1.19
Other - not specified	2					2		4.00	0.00
Other - Historical Preservation	1						1	5.00	0.00
Other - Maintainability	1						1	5.00	0.00
Other - Customer Requested	1						1	5.00	0.00

Table 149 – Rankings of Benefits in Adopting New Building Materials, Total Builder Populations

Following are tables showing the rankings of the most important benefits of adoption of new building materials by the there individual populations.

LnO									
Perceived Benefit	**N**	**No importance**	**1**	**2**	**3**	**4**	**5 - critically important**	**Mean**	**Std. Dev.**
Durability	36			1	2	15	18	4.39	0.73
Safety (reduced risk)	36	1	1	1	7	12	14	3.94	1.19
Affordability	36			3	10	12	11	3.86	0.96
Environmentally friendly	36		1	1	12	16	6	3.69	0.89
Ease of installation	36			5	11	13	7	3.61	0.96
Aesthetics	36		1	1	18	12	4	3.47	0.84
Reduced liability	35	1	3	3	10	10	8	3.40	1.33
Other - not specified	2					2		4.00	0.00
Other - Historical Preservation	1						1	5.00	0.00
Other - Maintainability	1						1	5.00	0.00

Table 150 – Rankings of Benefits in Adopting New Building Materials, LnO

Prime Contractors									
Perceived Benefit	**N**	**No importance**	**1**	**2**	**3**	**4**	**5 - critically important**	**Mean**	**Std. Dev.**
Durability	14			1	1	6	6	4.21	0.89
Safety (reduced risk)	14				4	4	6	4.14	0.86
Reduced liability	14				4	5	5	4.07	0.83
Ease of installation	14			1	2	7	4	4.00	0.88
Affordability	14				4	7	3	3.93	0.73
Aesthetics	14				4	8	2	3.86	0.66
Environmentally friendly	14		1	3	5	4	1	3.07	1.07
Other - Customer Requested	1						1	5.00	0.00

Table 151 – Rankings of Benefits in Adopting New Building Materials, Prime Contractors

"Top 200+"									
Perceived Benefit	**N**	**No importance**	**1**	**2**	**3**	**4**	**5 - critically important**	**Mean**	**Std. Dev.**
Durability	23				4	4	15	4.48	0.79
Reduced liability	23			1	2	5	15	4.48	0.85
Affordability	23			1	3	8	11	4.26	0.86
Safety (reduced risk)	23		2		3	5	13	4.17	1.23
Aesthetics	23			2	2	10	9	4.13	0.92
Ease of installation	23		1		2	12	8	4.13	0.92
Environmentally friendly	23	2	2	2	7	5	5	3.13	1.55

Table 152 – Rankings of Benefits in Adopting New Building Materials, "Top 200+"

When comparing the importance of perceived benefits of adopting new building materials between the individual populations it is seen that their perceptions are statistically significantly different based on a 0.10 significance level using ANOVA for the following perceived benefits: Reduced Liability, Aesthetics, and Ease of Installation.

Perceived Benefit	Total	LnO	Prime Contractors	“Top 200+”	Sig.
Durability	4.38	4.39	4.21	4.48	0.609
Safety (reduced risk)	4.05	3.94	4.14	4.17	0.721
Affordability	4.00	3.86	3.93	4.26	0.238
Reduced liability	3.88	3.40	4.07	4.48	**0.002**
Ease of installation	3.85	3.61	4.00	4.13	**0.099**
Aesthetics	3.75	3.47	3.86	4.13	**0.015**
Environmentally friendly	3.40	3.69	3.07	3.13	0.106

Table 153 – Comparison of Rankings of Benefits in Adopting New Building Materials

Additionally the importance of perceived benefits of adopting new building materials was broken down by job title and region for the LnO population. This can be seen in the following tables.

Construction Administrators considered Durability and Affordability to be equally critical. Respondents with all other job titles ranked Durability as the most important benefit in adoption of new building materials.

	Engineer		Facility Maintenance Supervisor		Architect		Construction Administration		Total	
	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N
Other	4.00	1	4.00	1	5.00	1	5.00	1	4.50	4
Durability	4.40	10	4.33	6	4.58	12	4.13	8	4.39	36
Safety (reduced risk)	3.70	10	3.83	6	4.33	12	3.75	8	3.94	36
Affordability	3.90	10	3.83	6	3.67	12	4.13	8	3.86	36
Environmentally friendly	3.80	10	3.33	6	4.08	12	3.25	8	3.69	36
Ease of installation	3.50	10	3.50	6	3.58	12	3.88	8	3.61	36
Aesthetics	3.10	10	3.33	6	3.67	12	3.75	8	3.47	36
Reduced liability	3.11	9	3.17	6	3.92	12	3.13	8	3.40	35

Table 154 – Rankings of Benefits in Adopting New Building Materials by Job Title

In the Pacific/Northwest regions, Affordability is ranked as most important, followed closely by Durability. Durability is ranked as the most important benefit in all other regions.

	South		Southwest		Pacific/Northwest		Atlantic/Northeast		Total	
	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N
Other	5.00	1			4.50	2	4.00	1	4.50	4
Durability	4.00	8	4.64	14	4.33	6	4.38	8	4.39	36
Safety (reduced risk)	3.25	8	4.21	14	4.17	6	4.00	8	3.94	36
Affordability	3.50	8	3.86	14	4.50	6	3.75	8	3.86	36
Environmentally friendly	3.25	8	3.86	14	3.83	6	3.75	8	3.69	36
Ease of installation	3.38	8	3.71	14	3.83	6	3.50	8	3.61	36
Aesthetics	3.13	8	3.50	14	3.67	6	3.63	8	3.47	36
Reduced liability	2.75	8	3.54	13	3.67	6	3.63	8	3.40	35

Table 155 – Rankings of Benefits in Adopting New Building Materials by Region

Respondents from the Distributor and Retailer populations were also asked to rate the importance (on a scale from 0 = no importance to 5 = critically important) of perceived benefits of adopting new building materials. They rated Profit Growth (mean = 4.43) followed by Sales Growth (mean = 4.16) as the most important benefits. Increasing Merchandise Breadth (mean = 3.07) was rated as the least important benefit.

Total									
Factor	**N**	**No importance**	**1**	**2**	**3**	**4**	**5 - critically important**	**Mean**	**Std. Dev.**
Profit Growth	69			1	7	22	39	4.43	0.74
Sales Growth	69			2	13	26	28	4.16	0.83
Competition	69		1	8	15	23	22	3.83	1.06
Relationship with Suppliers	68		4	8	16	19	21	3.66	1.20
Inventory Turnover Risks	68		1	10	20	17	20	3.66	1.10
Inventorying and Storage Costs	69		2	15	19	15	18	3.46	1.18
Material Handling Processes	68	1	1	16	28	12	10	3.16	1.09
Increasing Mechandise Breadth	68	1	8	10	27	10	12	3.07	1.27
Other - Quality	2						2	5.00	0.00
Other - Improved Customer Service	1						1	5.00	0.00
Other - Customer Demand (builders)	1						1	5.00	0.00

Table 156 – Rankings of Benefits in Adopting New Building Materials, Total Wholesaler and retailer populations

Wholesalers									
Factor	**N**	**No importance**	**1**	**2**	**3**	**4**	**5 - critically important**	**Mean**	**Std. Dev.**
Profit Growth	29				1	7	21	4.69	0.54
Sales Growth	29			2	3	11	13	4.21	0.90
Relationship with Suppliers	28			3	7	6	12	3.96	1.07
Competition	29		1	5	5	3	15	3.90	1.32
Inventory Turnover Risks	28			3	7	8	10	3.89	1.03
Inventorying and Storage Costs	29			3	10	7	9	3.76	1.02
Material Handling Processes	29			6	12	5	6	3.38	1.05
Increasing Mechandise Breadth	29		5	3	10	4	7	3.17	1.39
Other - Quality	1						1	5.00	0.00
Other - Improved Customer Service	1						1	5.00	0.00

Table 157 – Rankings of Benefits in Adopting New Building Materials, Wholesalers

Retailers									
Factor	**N**	**No importance**	**1**	**2**	**3**	**4**	**5 - critically important**	**Mean**	**Std. Dev.**
Profit Growth	40			1	6	15	18	4.25	0.81
Sales Growth	40				10	15	15	4.13	0.79
Competition	40			3	10	20	7	3.78	0.83
Inventory Turnover Risks	40		1	7	13	9	10	3.50	1.13
Relationship with Suppliers	40		4	5	9	13	9	3.45	1.26
Inventorying and Storage Costs	40		2	12	9	8	9	3.25	1.26
Increasing Mechandise Breadth	39	1	3	7	17	6	5	3.00	1.19
Material Handling Processes	39	1	1	10	16	7	4	3.00	1.10
Other - Consumer Demand (builders)	1						1	5.00	0.00
Other - Quality	1						1	5.00	0.00

Table 158 – Rankings of Benefits in Adopting New Building Materials, Retailers

When comparing the importance of perceived benefits of adopting new building materials between the individual populations it is seen that their perceptions are statistically significantly different based on a 0.10 significance level using ANOVA for the following perceived benefits Profit Growth, Relationship with Suppliers, and Inventorying and Storage Costs.

Factor	Total	Wholesalers	Retailers	Sig.
Profit Growth	4.43	4.69	4.25	**0.013**
Sales Growth	4.16	4.21	4.13	0.690
Competition	3.83	3.90	3.78	0.641
Relationship with Suppliers	3.66	3.96	3.45	**0.083**
Inventory Turnover Risks	3.66	3.89	3.50	0.149
Inventorying and Storage Costs	3.46	3.76	3.25	**0.078**
Material Handling Processes	3.16	3.38	3.00	0.156
Increasing Mechandise Breadth	3.07	3.17	3.00	0.585

Table 159 – Comparison of Rankings of Benefits in Adopting New Building Materials, Wholesalers

COMMENTS AND OPINIONS

Additional comments and opinions related to building materials and woodfiber-plastic composites were provided by several respondents from each of the populations.

LNO's

- The Navy (NAVFAC) needs to consider all new technologies and see that appropriate ones are added to our Guide Specifications. As it stands now with the impetus to use design/build for new and renovation work the contractors decides.

- There is a large range of wood fiber/plastic composites - the designer/purchaser must know if the particular product is correct for the intended use.

- The Govt, specifically our clients, Activities and Claimants, do not relish the concept of being the guinea pig for testing and evaluation of new materials. Same in Civilian Design and construction world.

- The specific type, quality, capability, and durability of an element or component will vary with the manufacturer and locale. It is therefore important to always follow manufacturer's recommendation in the use of material and to pay careful attention to the building code requirements in effect for a building's use and location.

- Extensive termite damage occurs to all wood structures in Hawaii/Tropics Areas.

- Extensive moisture, salt, mildew, and weathering occurs in the Hawaii/Tropics Areas.

- Wharve repairs w/more plastic composites to reduce early replacement parts caused by salt/insect deterioration.

- Why the emphasis on woodfiber-plastic composites? Please send complimentary study summary.

- (in response to request for ranking of knowledge about woodfiber-plastic composites) Note: not much out there.

- My group is responsible for the creation of construction specificaitonis for all projects in the Atlantic Divisioin AOR. WE require that all materials are specified using Navy guides specifications. This ensures the Navy receives high quality products that that have a proven track record for durability. Most of our durability problems are related to improper installation practices or the substitution of inferior matrerials by the Contractors.

- Woodfiber-plastic composites (WPC) has great potential for energy efficient window systems. Aluminum windows (even with a "thermal break") don't perform well w/blocking movement of heat.

- Local climatic conditions must play a major role in the selection of building materials.

Prime Contractors

- All public projects have material specifications allowing for little substitution.

- Keep up the good work. We employ 3 Penn State engineers. They are great.

- Good luck on your research.

- Generally, these types of products are either specified or not specified.

- Building materials are generally more user friendly than in the past. Also, they are much more environmentally effective. WPC products have advantages (e.g. consitancy in quality), but are also not always cost effective.

"Top 200+" Builders

- We are looking forward to a true turn-key metal framing contractors. Anything other than wood could help our industry.

Wholesalers

- "Redwood the Renewable Resource"

- Rot free, low maintenance material should be used more in our industry. Costs must be controlled for many viable situations.

- Wood and wood products come from our only renewable natural resource! TREES!!

- When Trex came out they were the best new product in a long time - Now everyone else seems to have a better product. LVL is best new product in years.

- We don't handle any of these items - Funter Lumber

- We don't handle this product category

- Our company is a wholesale distributor.

- We need a product that will stain like wood - made from a Moisture Shield product.

Retailers

- In regards to selection of new items, although I have a major influence in this process my views are not always supported by upper management. I feel new products are critical to growth, but this view

- Many, not all usually are not field tested properly before being introduced. Also, geography is not considered. Just because a product is good in the south doesn't mean it will perform in the NW.

- Composites are priced high at this time. I think that is the reason it isn't as strong as it should be.

- Our firm does not distribute any of the products in this survey.

- Composite material is a great idea! The only problem I have with it is, it too expensive to produce! Cut the production cost and I could sell tons of it!!

- They will continue to take market share from wood products.

- Too much plastic used today!

Figures

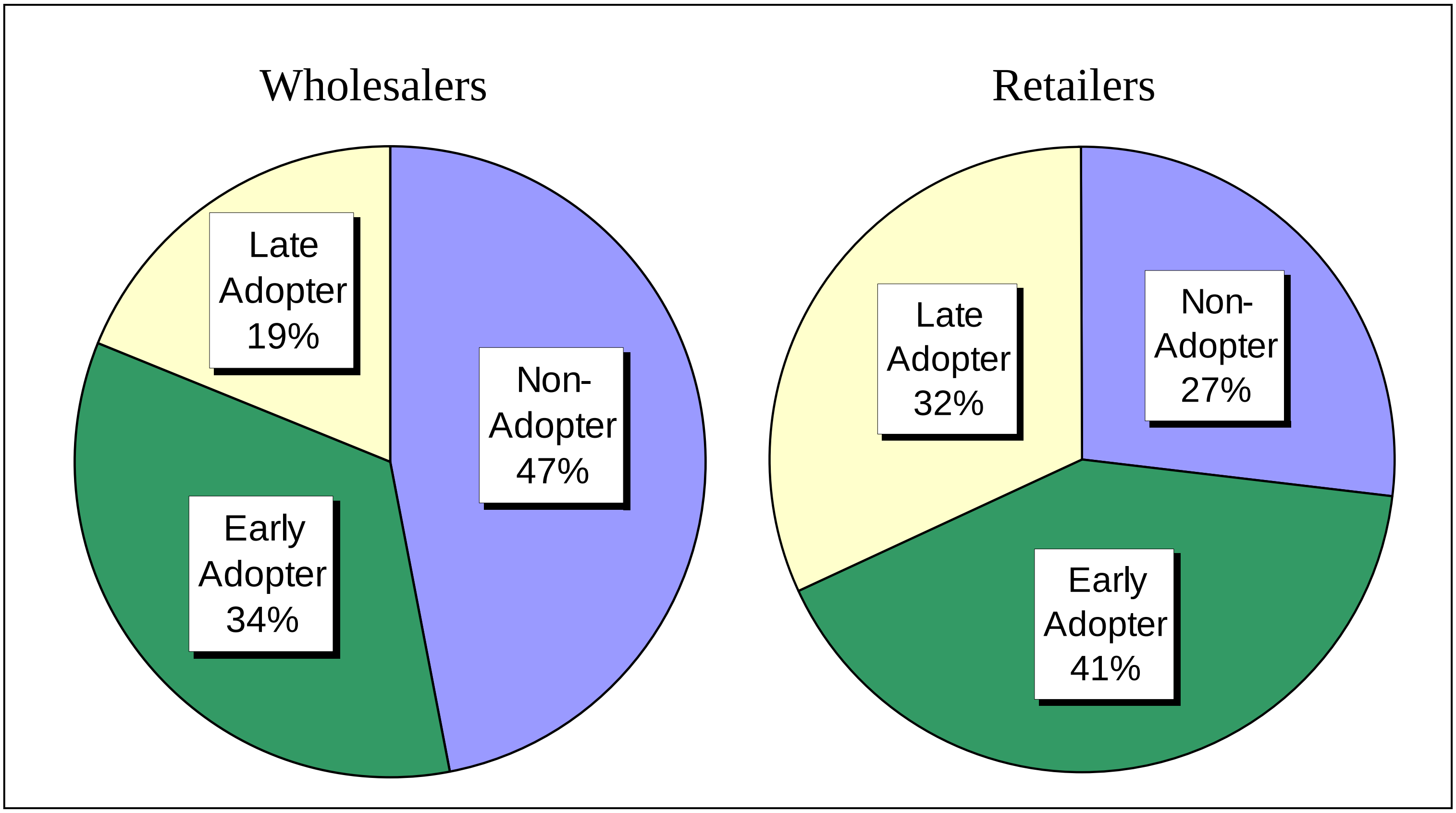


Figure 1: Adoption Phase of Wholesalers and Retailers in Relation to WPC

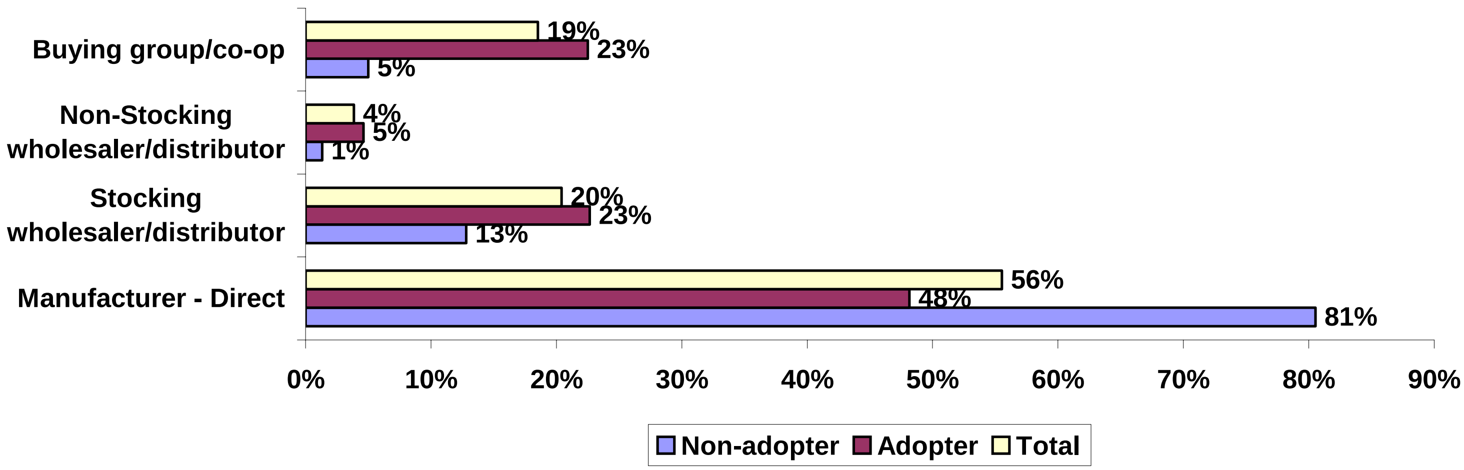


Figure 2 – Percentage of Purchases made from that Source

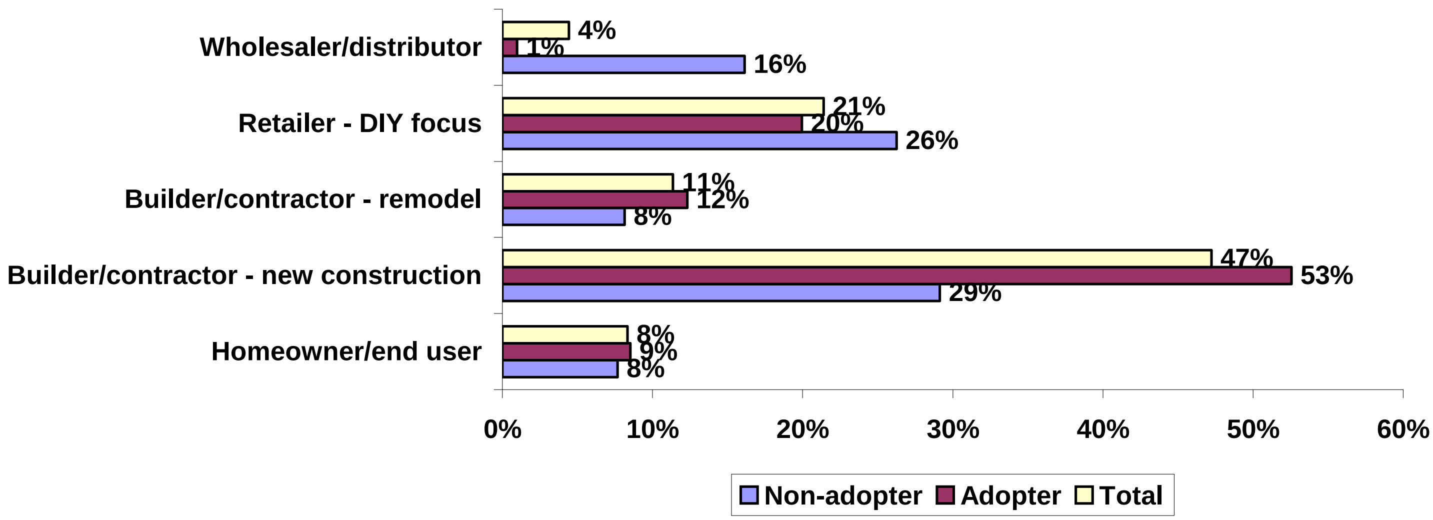


Figure 3 – Percentage of Sales made to that Customer Type

Figure 4 - Major Naval Facilities within the United States

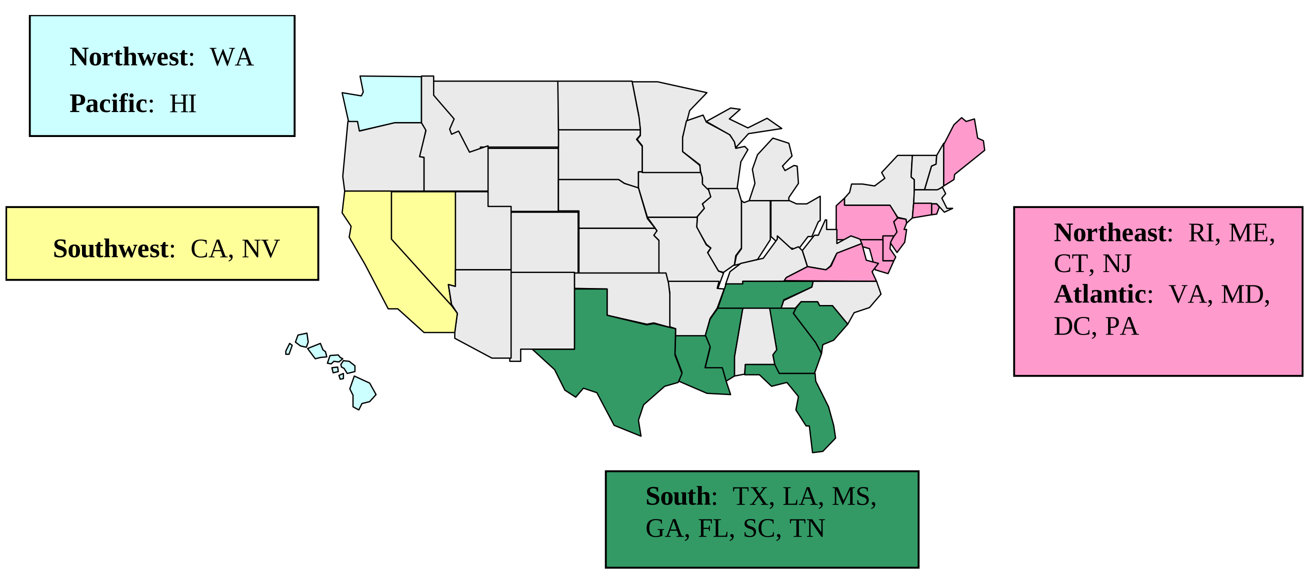


Figure 5 – Naval Base Regions by State

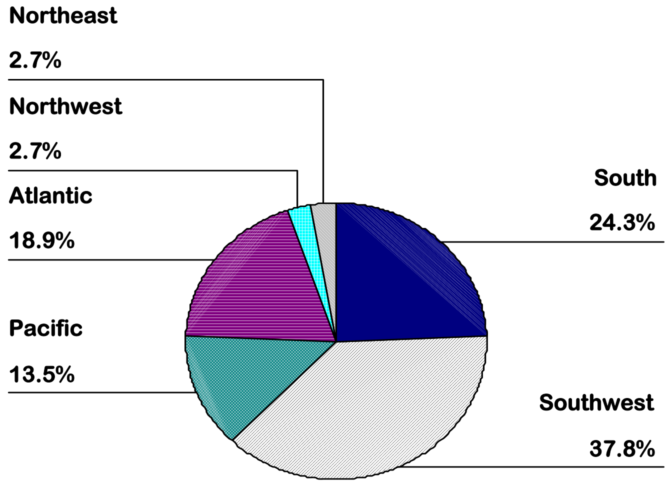
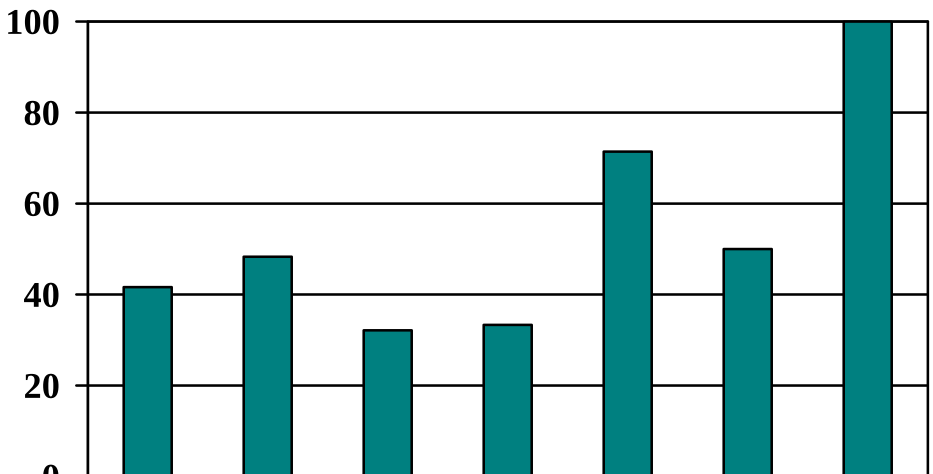


Figure 6 - Overall Response Distributed by Region (n = 37)



	TOTAL (37/89)	Southwest (14/29)	South (9/28)	Atlantic (7/21)	Pacific (5/7)	Northwest (1/2)	Northeast (1/1)
Response %	41.6	48.3	32.1	33.3	71.4	50	100

Figure 7 - Response Rates within Regions

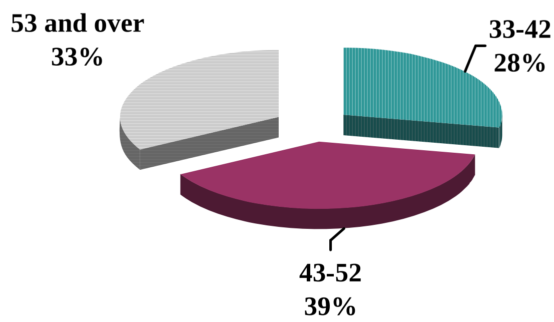


Figure 8 - Age Groups of LnO Respondents

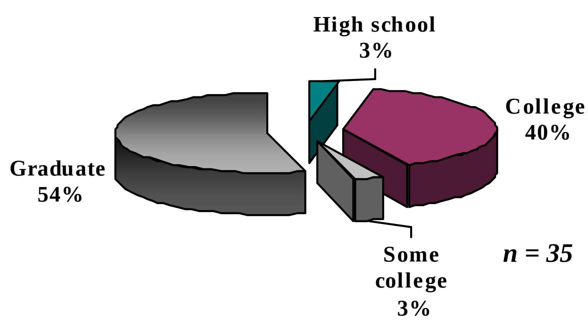


Figure 9 - Education Level of LnO Respondents

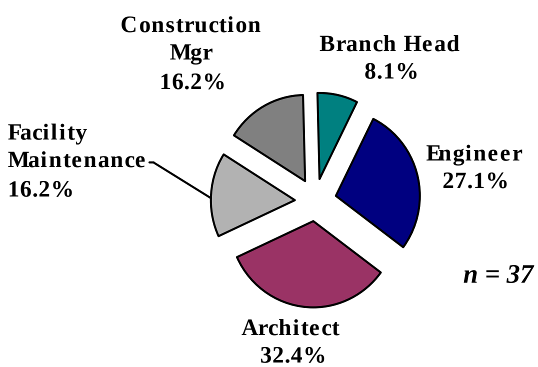


Figure 10 - Job Titles of LnO Respondents

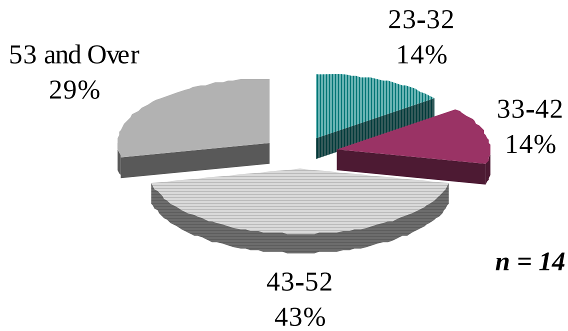


Figure 11 – Age of Prime Contractors Respondents

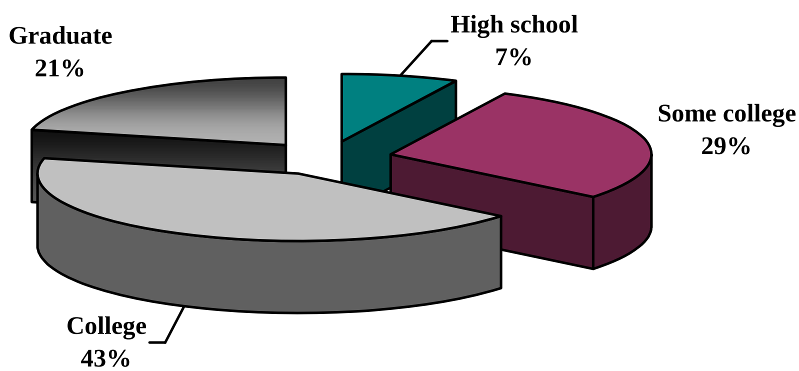


Figure 12 – Education Level of Prime Contractors Respondents

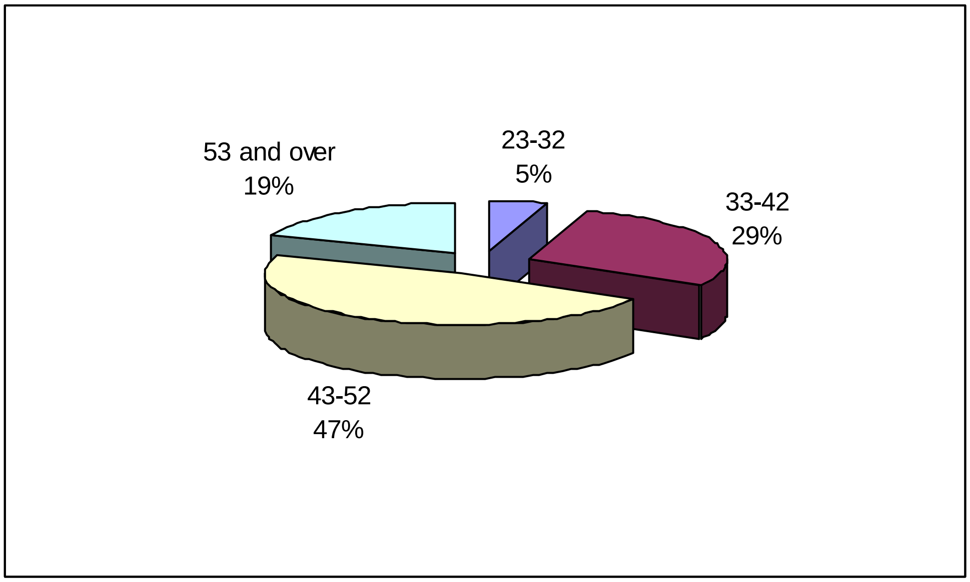


Figure 13 – Age of "Top 200+" Respondents

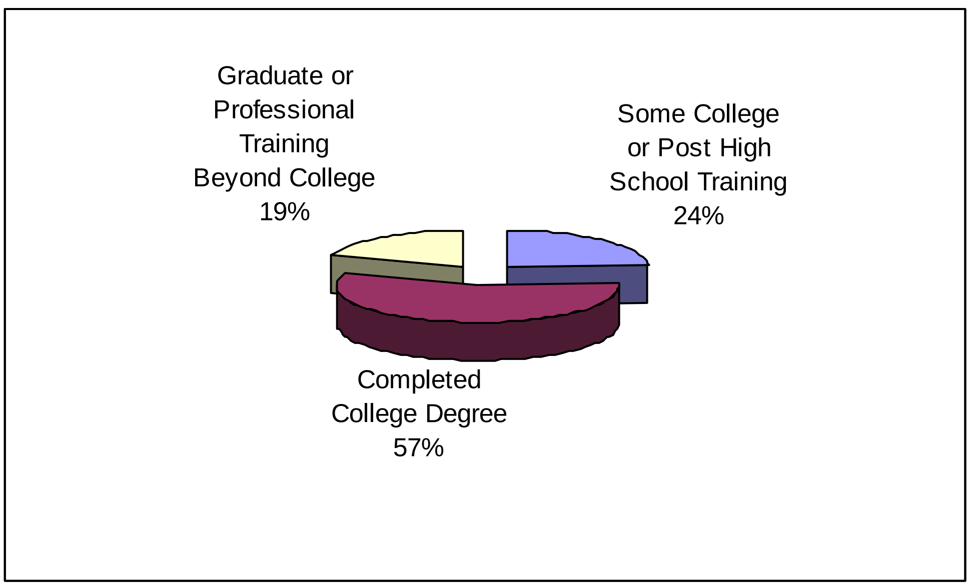


Figure 14 – Education Level of "Top 200+" Respondents

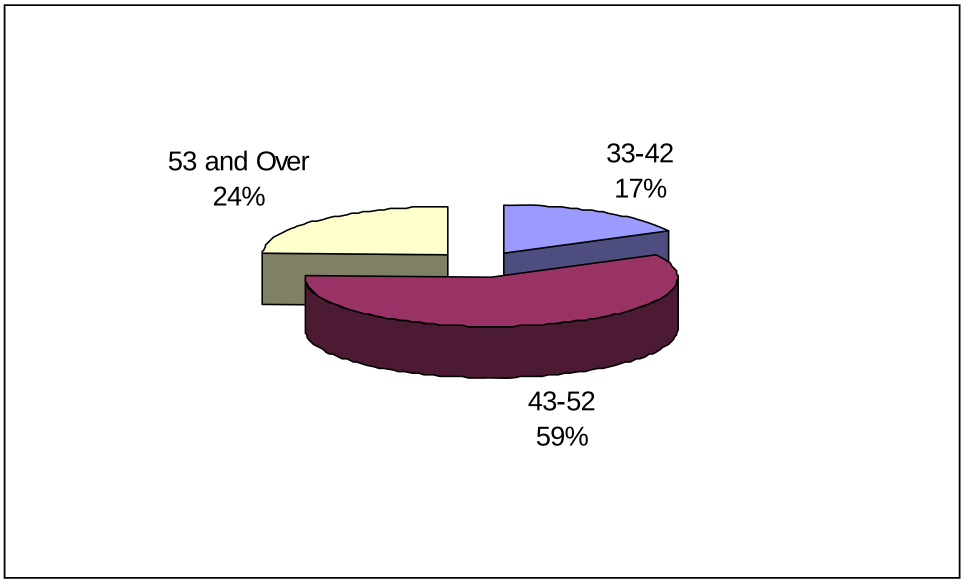


Figure 15 – Age of Distributor Respondents

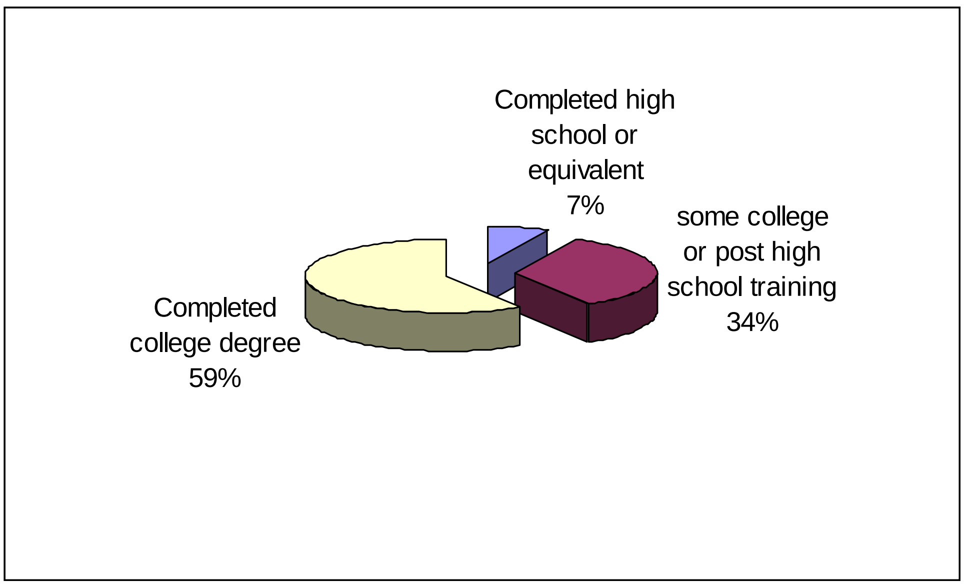


Figure 16 – Education Level of Distributor Respondents

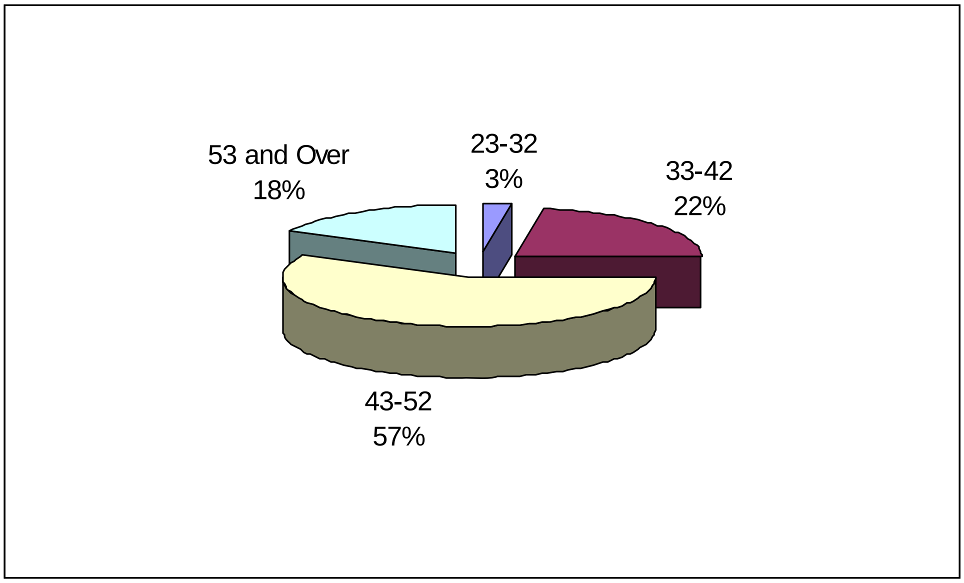


Figure 17 – Age of Retailer Respondents

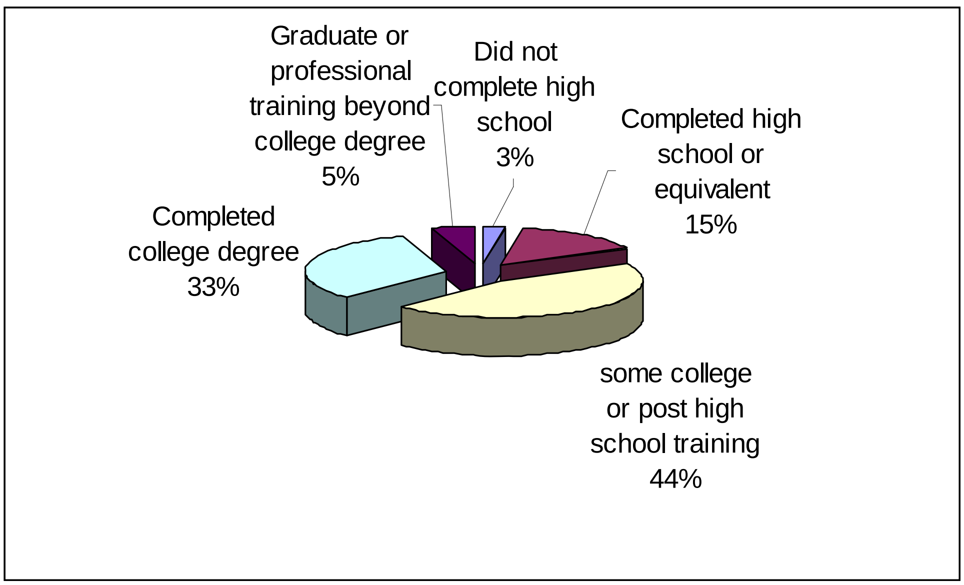


Figure 18 – Education Level of Retailer Respondents

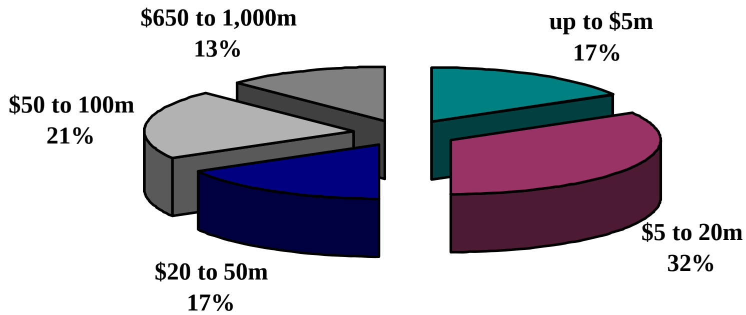


Figure 19 - Expenditures for Repair/Maintenance by Percent of Respondents, 2001

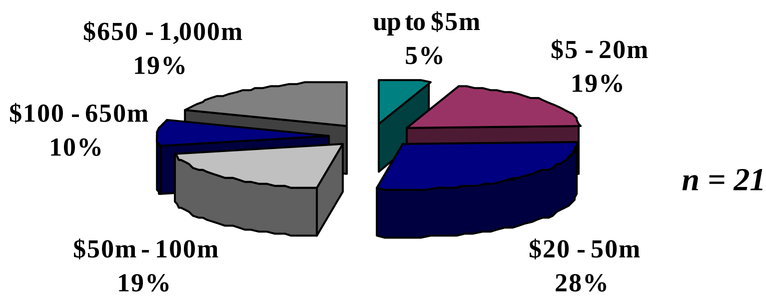


Figure 20 - Expenditures for Building Construction by Percent of Respondents, 2001

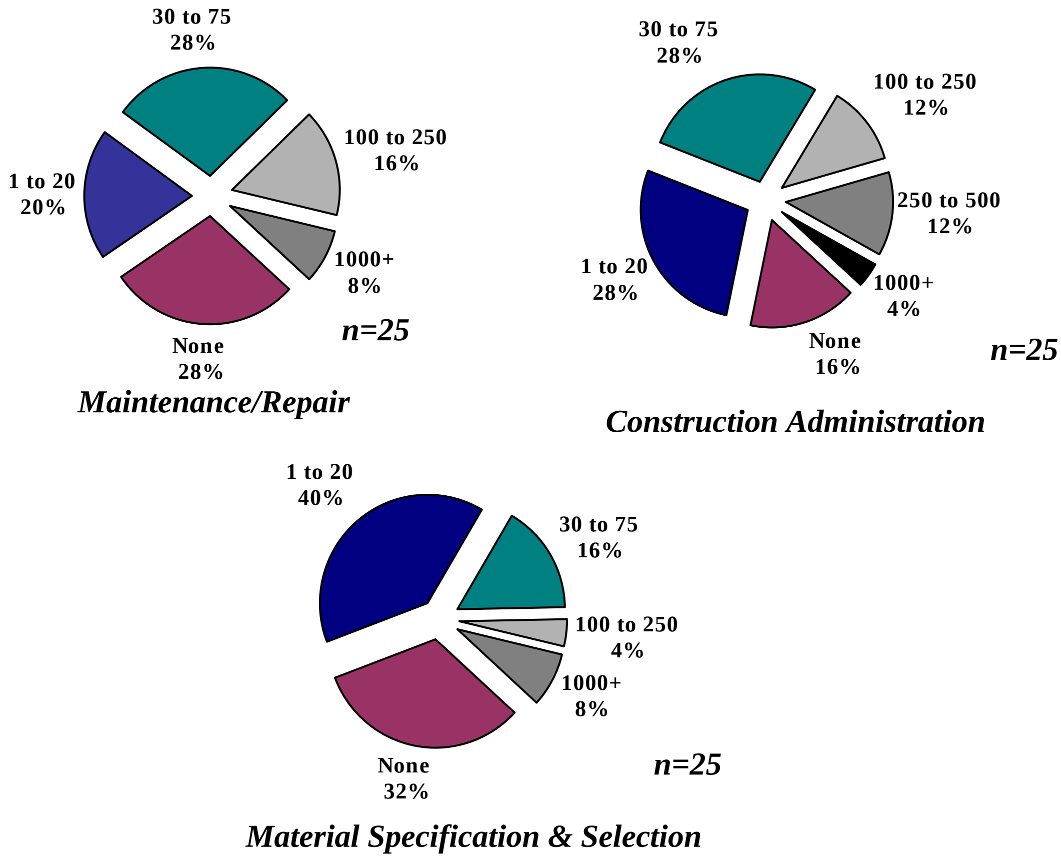


Figure 21 - Personnel Counts

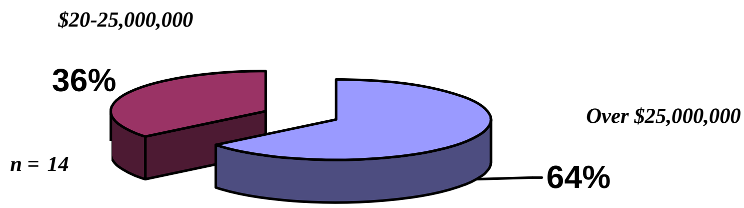


Figure 22 – Total Sales Revenue, 2001

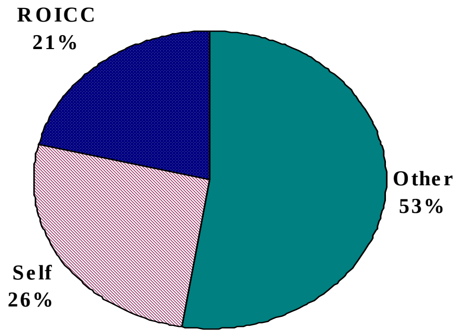


Figure 23 – Selection Decisions: Self, ROICC, Other (n = 38)

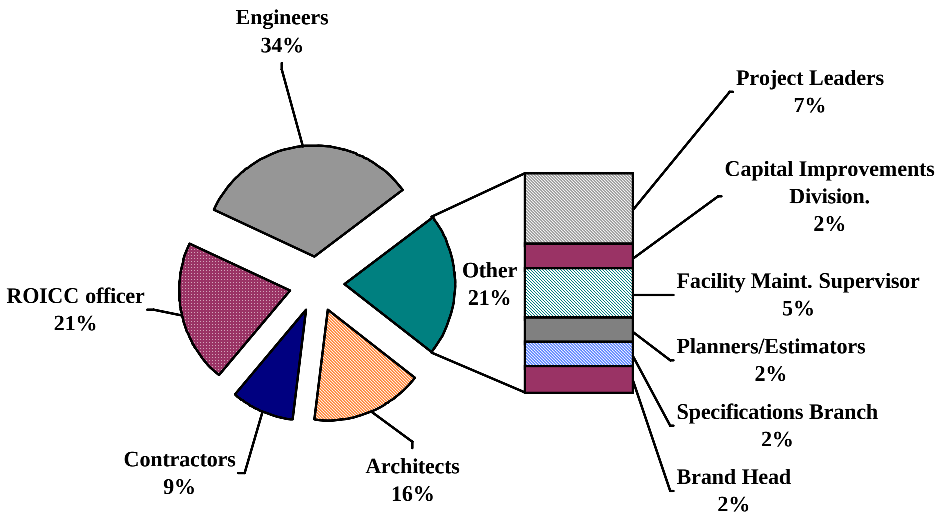


Figure 24 - Building Material Selection Decisions by Job Title (n = 46)

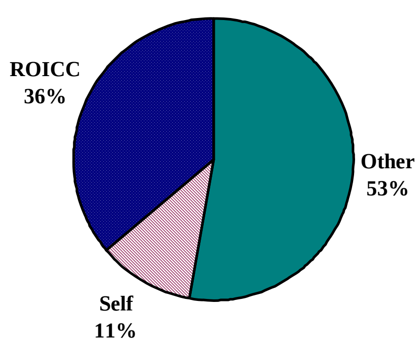


Figure 25 – Purchasing Decisions: Self, ROICC, Other (n = 36)

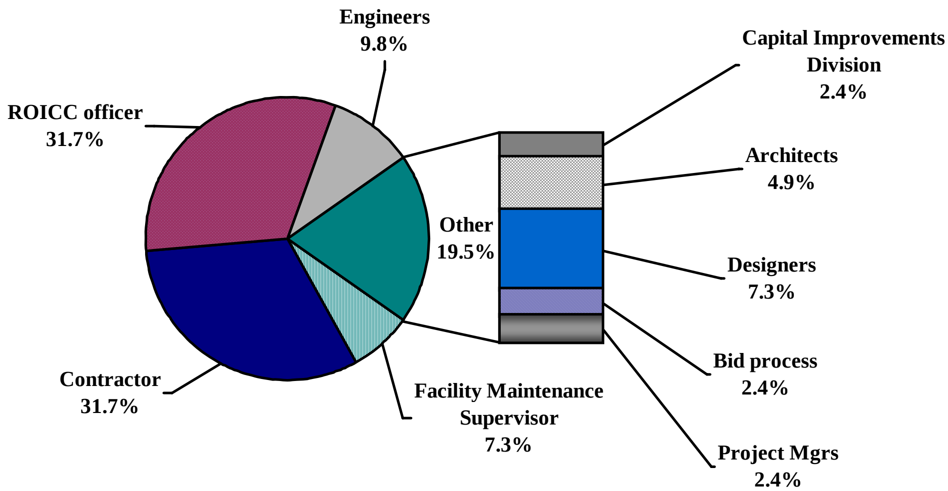


Figure 26 - Purchasing Decisions by Job Title (n = 41)

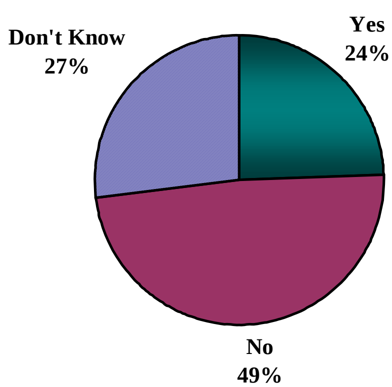


Figure 27– Woodfiber-Plastic Composite Use

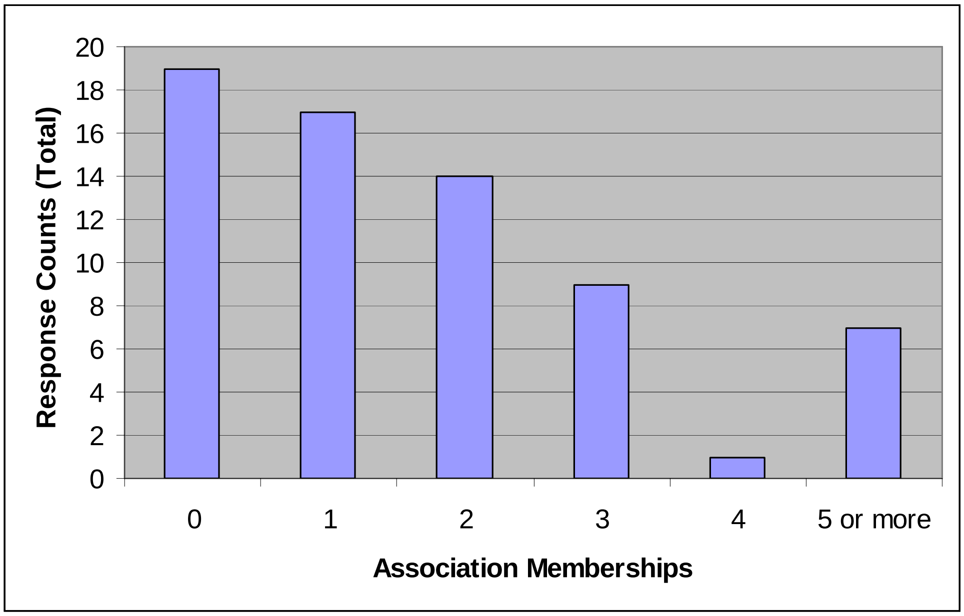


Figure 28 – Membership in Professional Associations, Total

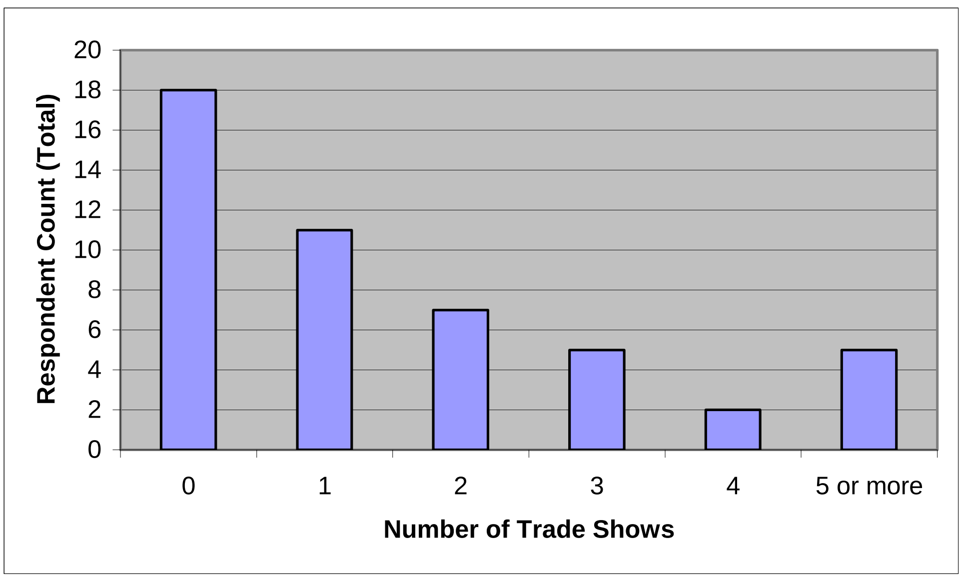


Figure 29 – Trade Show Attendance, Total

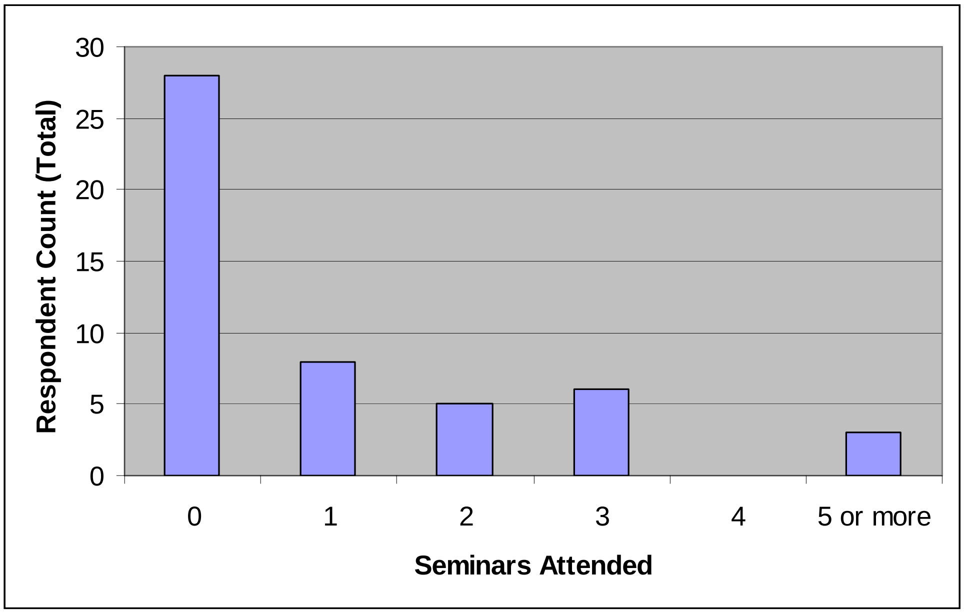


Figure 30 – Seminar Attendance, Total

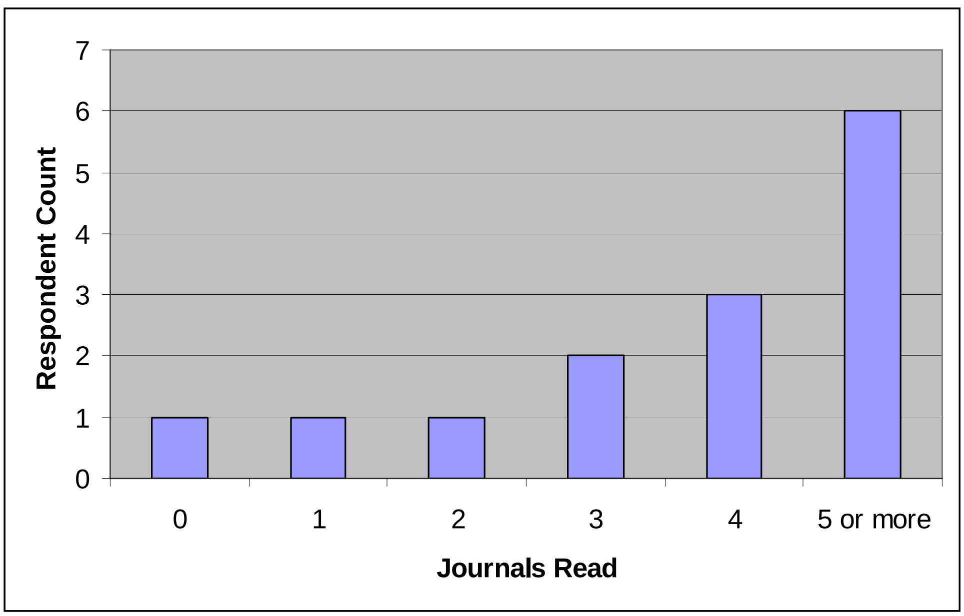


Figure 31 – Number of Trade Journals Read

Appendices

Appendix 1: Cover Letter and Request for Assistance for Liason Officers

I am writing to ask your help in a study sponsored by ONR (Navy Advanced Wood Composites) with cooperation from the Naval Facilities Engineering Service Center (Port Hueneme, CA). This study is part of the Navy's effort to identify current building material usage and to expedite the transfer of appropriate innovative research into new products.

You are being contacted because Jerry Dummer, whom most of you know, and who is my current supervisor in Code ESC63 at the Shore Facilities Department at NFESC suggested you may be of assistance. We are asking for your help in providing contact information for personnel who are most directly involved in maintenance and repair of facilities, construction administration, and specifying and selecting construction materials. Your responses will be used to direct the questionnaire for this study to those personnel who are the most knowledgeable and experienced with building materials.

We recognize your time is limited and have made every attempt to make it easy for you to provide this information. This form and the future questionnaire provided to the candidate personnel will be brief and should only take approximately 15 minutes to complete. We have attached a form to this message that can be completed by following these steps:

1. Open the form attachment and enter your responses. *(You will need to use the TAB key to move the cursor to the next response item.)*
2. After you complete this form, please save the completed form.
3. Touch the "reply" command on your computer. Attach the completed form and return it via e-mail to me at hoffardta@nfesc.navy.mil and a copy to kdb9@psu.edu.

This form, and the subsequent questionnaire that personnel will receive, is voluntary and **completely confidential.** Summary information will be reported in the study results. We would also be pleased to provide you and all participants with a **complimentary summary of the study results** as a token of appreciation. Just mention that you would like a copy of the results in your e-mailed response.

If you have any questions about this study, I can be reached at (805) 982-1059 or my e-mail address. You can help the Navy and us very much by taking a few minutes to provide the requested information. If for some reason, you prefer not to respond, would you please let me know? Also, if you are not able to open the attached form, would you also let me know? Your help is truly essential to the study's success.

Sincerely,
Theresa Hoffard
{title}
ESC63 Waterfront Materials
Naval Facilities Engineering Service Center

NAVY-MARINE CORPS LIAISON TEAM
REQUEST FOR POINTS OF CONTACT

Purpose: The purpose of this request is to identify personnel that are involved in base maintenance and repair of facilities, construction administration, and specifying and selecting construction materials for the Navy.

This information will be used for the **Navy Advanced Wood Composite Project** sponsored by ONR . The project is a cooperative effort of NFESC and Penn State University to direct the development of new materials with improved performance capabilities for the Navy. It is important to solicit opinions from diverse groups within the Navy to help expedite the transfer of appropriate innovative research into new products.

Benefit: *Your answers will be allow us to contact the candidate personnel with tailored surveys based on their involvement in construction on the following topics:*

- Problem and durability issues for building materials in use
- Current and potential building material usage
- Substitution potential of new building materials
- Important characteristics in the selection and purchase of building materials

Addressing these issues will ultimately benefit the candidate personnel and their activities by bringing innovative, cost-effective new products to the market that provide durability advantages over current materials for Navy construction.

- **Instructions**: Please provide personnel contact information [name, title, phone (with area code), and e-mail address] for those POC's across your current (or prior) region of operation in the three categories listed below. *Please provide up to five contacts for each category if possible, and preferably those personnel with the most experience and knowledge of building materials.*

This form is short and should take only 10-20 minutes to complete**.**
RESPONSE REQUESTED BY (DATE). Your cooperation is greatly appreciated.

- MAINTENANCE AND REPAIR OF FACILITIES

NAME	TITLE	PHONE	E-MAIL

- CONSTRUCTION ADMINISTRATION

NAME	TITLE	PHONE	E-MAIL

- SPECIFYING & SELECTING CONSTRUCTION MATERIALS

NAME	TITLE	PHONE	E-MAIL

*Please provide YOUR contact information for reference:

NAME	TITLE	PHONE	E-MAIL

Appendix 2: LnO Population Contact List

ID	NAME	REGION	TITLE	CATEGORY	LNO
1	LCDR John D' Angelo	southwest	Production Control Officer	Maintenance & Repair	Bob Schard
2	Tom Carr	southwest	Deputy PWO	Maintenance & Repair	Bob Schard
3	Joe Culhane	southwest	Maintenance Management	Maintenance & Repair	Bob Schard
4	Ed Ruckle / James Page	southwest	Engineer	Construction Administration	Bob Schard
5	LT Kristian Barton	southwest	Engineer	Construction Administration	Bob Schard
6	Joe Roby	southwest	Construction Mgm Tech	Construction Administration	Bob Schard
7	Bill Crowley	southwest	Construction Mgm Tech	Construction Administration	Bob Schard
8	David Kimes	southwest	Engineer	Construction Administration	Bob Schard
9	James Cauthorn	southwest	Supv In-house Design Team	Specifying & Selecting	Bob Schard
10	John Wootton	southwest	Architect	Specifying & Selecting	Bob Schard
11	Tom Blount	southwest	Engineer	Specifying & Selecting	Bob Schard
12	Nelly Totty	southwest	Engineer	Specifying & Selecting	Bob Schard
13	Howard Sweatte	southwest	Architect	Specifying & Selecting	Bob Schard
14	Hiram Pang	Pacific	R311	Construction Administration	Pat Habecker
15	CDR Rios	southwest	PWO/NBC	Maintenance & Repair	Jim Senescall
16	LCDR Autry	southwest	ROICC/SWD/Coronado	Construction Administration	Jim Senescall
17	Roger Urbi	Pacific	Con Ops	Construction Administration	Pat Habecker
18	Neal Kawamoto	Pacific	K052 Supervisory Civil Engineer	Construction Administration	Pat Habecker
19	Darrel Tano	Pacific	DPM406	Specifying & Selecting	Pat Habecker
20	Pat Habecker	Pacific	ROPS-H	Specifying & Selecting	Pat Habecker
21	Richard Nagashima	Pacific	Architect	Maintenance & Repair	Lynn Tanaka
22	Jerry Hackett	Northwest	(not given)	Maintenance & Repair	Charles Greely
23	Mike Sitto	southwest	Engineer	Specifying & Selecting	Linda Geldner
24	Ed Hanlon	southwest	Engineer	Construction Administration	Linda Geldner
25	Ed Gallaher	Atlantic	Eng & Design, Head of Specs Branch	Specifying & Selecting	Rick Butler
26	Neil DuVernay	Atlantic	Eng & Design, Architect	Specifying & Selecting	Rick Butler
27	Mike Reavis	south	Facilities Engineering Div Dir	Maintenance & Repair	William G. Robins
28	Larry Hill	south	Special Programs Div Dir	Maintenance & Repair	William G. Robins
29	Ray Gay	south	ROICC Advocate	Construction Administration	William G. Robins
30	Bill Woodard	south	ROICC Advocate	Construction Administration	William G. Robins
31	Steve Marsh	south	ROICC Advocate	Construction Administration	William G. Robins
32	Byron Geddings	south	Architect	Specifying & Selecting	William G. Robins
33	Robert Moose	south	Architect	Specifying & Selecting	William G. Robins
34	Jim Spivey	south	Electrical Engineer	Specifying & Selecting	William G. Robins
35	Hugh Odom	south	Mechanical Engineer	Specifying & Selecting	William G. Robins
36	Karen Kraft	south	Interior Designer	Specifying & Selecting	William G. Robins
37	Jim Morgan	south	APWO	Maintenance & Repair	Thomas Bruder
38	Dan Schickler	south	APWO	Maintenance & Repair	Thomas Bruder
39	John Carine	south	REICC	Construction Administration	Thomas Bruder
40	Bill Carmichael	south	REICC	Construction Administration	Thomas Bruder
41	Al Paivandy	south	PM	Specifying & Selecting	Thomas Bruder
42	Michael Jackson	south	PM	Specifying & Selecting	Thomas Bruder
43	Clinton Odiorne	Northwest	General Engineer	*all three	Clinton Odiorne
44	Jack McCarthy	south	Structural Engineer	Specifying & Selecting	Robbie Wiksell
45	Bob Goklani	southwest	ROICC Engineer	Construction Administration	Linda Geldner
46	Ken Conboy	southwest	ROICC Engineer	Construction Administration	Linda Geldner/Maz Nazzal
47	Jim Lorenz	southwest	ROICC Engineer	Construction Administration	Linda Geldner/Maz Nazzal
48	Pete Bautista	southwest	ROICC Engineer	Construction Administration	Linda Geldner/Maz Nazzal
49	Bill Fallaw	southwest	ROICC Engineer	Construction Administration	Linda Geldner/Maz Nazzal
50	Anthony Fairchild	southwest	Architect Project Leader	Specifying & Selecting	Linda Geldner/Maz Nazzal
51	Hugh Wood	southwest	Architect Project Leader	Specifying & Selecting	Linda Geldner/Maz Nazzal
52	Maz Nazzal	southwest	Architect Project Leader	Specifying & Selecting	Linda Geldner/Maz Nazzal

ID	NAME	REGION	TITLE	CATEGORY	LNO
53	LCDR Fred Broome	south	ROICC Office, Barksdale AFB, LA	Construction Administration	David Warren
54	Jimmy Elmore	south	ROICC Office, South Carolina	Construction Administration	David Warren
55	Gil Robins	south	Architectural Branch Head, SC	Specifying & Selecting	David Warren
56	Bob Viele	south	Architectural Specialties Branch Head, SC	Specifying & Selecting	David Warren
57	Will Beverly	south	Civil Branch Head, SC	Specifying & Selecting	David Warren
58	Mark Brown	south	Mechanical/POL Branch Head, SC	Specifying & Selecting	David Warren
59	Pete Parbot	southwest	Head of Engineering Facilities, Utilities	Maintenance & Repair	Ronald Gilchrist
60	Lou Cavagnaro	southwest	ROICC Advocate	Construction Administration	Ronald Gilchrist
61	Richard Barksdale	southwest	Field Team Advocate	Construction Administration	Ronald Gilchrist
62	Jim Ward	southwest	Chief Engineer	Specifying & Selecting	Ronald Gilchrist
63	Danny Obrero	Pacific	Superisory Engineering Technician	Construction Administration	Brian Shono
64	Pat Franklin	south	Director, Base Operation Support Business Line	Maintenance & Repair	Chip Bailey
65	Carl Dinge	south	Head of Specification Branch	Specifying & Selecting	Chip Bailey
66	John Potts	Atlantic	Facilities Maint. Spec. Supv.	Maintenance & Repair	Rick Butler
67	Gordon Spence	Atlantic	Maintenance Director	Maintenance & Repair	Rick Butler
68	Barry Callis	Atlantic	Facilities Maintenance Spec	Maintenance & Repair	Rick Butler
69	Alan Johnson	Atlantic	Architect	Specifying & Selecting	Rick Butler
70	John Salley	Atlantic	Architect Supervisor	Specifying & Selecting	Rick Butler
71	Jim Smith	Atlantic	Architect	Specifying & Selecting	Rick Butler
72	Paul Russel	Atlantic	Engineering Technician	Specifying & Selecting	Rick Butler
73	Ray Bunch	Atlantic	EFD Architect Brand HD	Specifying & Selecting	Rick Butler
74	Roy Morris	Atlantic	HD, Fac Mgt & Engrg Branch	Maintenance & Repair	Deborah Senchak
75	Jack Galvin	Atlantic	HD, Fac Mgt Section	Maintenance & Repair	Deborah Senchak
76	Bob Kelley	Atlantic	HD, Fac Engr section	Maintenance & Repair	Deborah Senchak
77	Rudy Perkey	Atlantic	Maintenance Fac Innov & Crit Engr	Maintenance & Repair	Deborah Senchak
78	John McLaren	Atlantic	HD, Component Support, Construction Div	Construction Administration	Deborah Senchak
79	Brenda Norton	Atlantic	ROICC Support	Construction Administration	Deborah Senchak
80	Bill Colden	Atlantic	Head, ROICC OPS	Construction Administration	Deborah Senchak
81	Susan Houser	Atlantic	Spec Branch Section HE	Specifying & Selecting	Deborah Senchak
82	David Curfman	Atlantic	Dir Engr Innov & Crit Office NAVFAC	Specifying & Selecting	Deborah Senchak
83	Steve Zavoyski	south	Engineering Director, PWC Jacksonville Region	Maintenance & Repair	Chip Bailey
84	Steve Meagher	Northeast	Structural engineer, PW Naval Submarine Base, New London,	Maintenance & Repair	Dawn C. Kincaid, P.E., R.E.M.
85	Tom Wetricht	Mediterranean	FMED PWD NSA Bahrain	Maintenance & Repair	Greg Wilderman
86	Doug Greer	Atlantic	COE Design Office in Winchester, VA	Specifying & Selecting	Greg Wilderman
87	Jack Ham	Mediterranean	COE Field Office in Bahrain	Construction Administration	Greg Wilderman
88	Clarence Vaughn	south	Engineering Director, NCBC Gulfport, Code 430	Construction Administration	Chip Bailey
89	Matt Schultz	south	Deputy PWO, NCBC Gulfport	Maintenance & Repair	Chip Bailey
989	Ferrigno	Atlantic	Structural engineer, PW Naval Submarine Base, New London,	Maintenance & Repair	recommended by Steve Meagher

Appendix 3: Prime Contractor Population Contact List

COMPANY	CONTACT	ADDRESS	PHONE
Actus Corporation	Howard McCormick	221 Gateway Road West, Ste 405 Napa, CA 94558-6279	707-252-7511
All Star Maintenance Inc.	Project Manager	12250 El Camino Real San Diego, CA 92130	858-259-0900
Allen L Bender, Inc.	Barbara Beck, Contracts Supervisor	2798 Industrial Blvd West Sacramento, CA 95691	916-372-2190
Anderson Columbia Co., Inc.	David Lachowsky	358 West Nine Mile Road Pensacola, FL 32534	850-494-1800
Arctic Slope Construction Inc Formerly Facil Syst Engr Corp(Fsec)	Carol, Contracts Supervisor	100 East Corson Street Pasadena, CA 91103	626-685-6600
Arena Construction Co Inc	Project Manager	45 Knollwood Road Elmsford, NY 10523	914-592-1155
Atkins Benham Constructors, Inc.	Roy Carlisle	9400 North Broadway Oklahoma City, OK 73114-7401	405-478-5353
Baker Support Services, Inc.	Dave Ebbett, Project Manager	4801 Spring Valley Road Dallas, TX 75244	972-991-0800
Barclay White/Coakley Construction	Project Manager	16 South Summit Avenue, Suite 300 Gaithersburg, MD 20877	
Berger/Abam Engineers, Inc.	Jeff Feeney, Project Manager	2005 5th Ave, 3rd Floor Seattle, WA 98121	206-374-9790
Bill Harbert Construction	Gary Savage, VP, U.S. Operations	820 Shades Creek Parkway Birmington, AL 35209	205-802-2800
Blinderman Const Co Inc	Kurt Scherkenbach, Equipment Manager	707 Lake Cook Road, Suite 310 Deerfield, IL 60015	847-564-2800
Bodell Construction Co.	Jerry Smith, Project Manager	P.O. Box 30246 Honolulu, HI 96820	808-422-4885
Burns And Roe Services Corp.	Bernie Kraai, Deputy Director	800 Kinderkamack Road Oradell, NJ 07649	201-265-2000
C Construction Co Inc	Tim Rutledge	P.O. Box 8270 Tyler, TX 75711	903-597-1500
C.E. Wylie Construction Co.	Sharon Wylie	3777 Ruffin Road San Diego, CA 92123	858-571-4911

COMPANY	CONTACT	ADDRESS	PHONE
Centennial Contractors Enterprises,Inc.	Marvin Woolard, Senior Quality Control Manager	8500 Leesburg Pike, Suite 500 Vienna, VA 22182	757-440-1177
Charles E.Smith Construction Service	Project Manager	2345 Crystal Drive, Suite 900 Arlington, VA 22202	703-769-5616
Chianelli Building Corporation Dba Cbc Enterprises, Inc.	Mark Lavin	301A Western Blvd Jacksonville, NE 28546	910-219-3253
Clark Nexsen (Fka Clark, Nexsen, Barbieri, Gibson)	Project Manager	6160 Kempsville Circle, Suite 200A Norfolk, VA 23502	757-622-2800
Clark/Blinderman/Knight, Llc	Silvia Ortega	216 S. Jefferson Street Chicago, IL 60661	312-474-5500
Cullum Constructors, Inc.	Joe Anonie, Purchasing Agent	P.O. Box 40368 Charelston, SC 29423-0368	843-554-6645
Del-Jen, Inc.	Project Manager	P.O. Box 2471 Clarksville, TN 37042	931-552-0232
Design Partners Inc.	Vernon Inoshita, President	1580 Makaloa Street, Suite 1100 Honolulu, HI 96814	808-949-0044
Dick Pacific Construction Co Ltd Fka Fletcher Pacific Constrn Co Ltd	Wilfred Ideue, Vice President	707 Richards Street, Suite 400 Honolulu, HI 96813	808-521-7861
Dillingham Construction Pac. Ltd. Dba Hawaiian Dredging & Constr Co.	Project Manager	P.O. Box 4088 Honolulu, HI 96812-4088	
Donohoe Construction Co., Inc.	Steve Hunsberger, Project Manager	2101 Wisconsin Avenue N.W. Washington, DC 20007	202-333-0880
Dzs/Baker Llc	Project Manager	98-790 Moanalua Road Aiea, HI 96701	864-241-8300
Earth Tech, Inc	Randy Hunter	100 West Broadway, Suite 240 Long Beach, CA 90802-4443	562-951-2000
Encompass Mechanical Services	Project Manager	13035 Middletown Industrial Blvd. Louisville, KY 40223	502-244-2596
Ewing, Cole, Cherry, Brott	Richard Delaney, Project Manager	100 N. 6th St. Fed. Res. Bank Bldg. Philadelphia, PA 19106	215-923-2020
Gibbs Construction Company, Inc.	Tom Buddy, Purchasing Agent	5736 Citrus Blvd Harahan, LA 70123	504-733-4336
Greenhut Construction Company, Inc.	Kelli Williams, Project Manager	23 South A Street, P.O. Box 12603 Pensacola, FL 32591-2603	850-433-5421

COMPANY	CONTACT	ADDRESS	PHONE
Harkins Builders Inc.	Larry Kraemer	2201 Warwick Way Marriotsville, MD 21104	410-750-2600
Harper/Nielsen Dillingham Builders	Project Manager	2241 Kettner Blvd, Ste 300 San Diego, CA 92101	619-233-7900
Harris/Cash Joint Venture	Elliott Boone, Executive President	5772 Bolsa Avenue Huntington Beach, CA 92649	714-895-2072
Healy Tibbitts Builders, Inc.	Project Manager	99-994 Iwaena St. Suite A Aiea, HI 96701	808-487-3664
Hewett-Kier Construction, Inc.	James Hewitt, President	3451 NW 14th Ave. Pompano Beach, FL 33064	954-946-4224
Hitt Contracting Inc.	Hank Kemp, Senior Project Manager	2457 Aviation Ave., Suite 100 North Charleston, SC 29406	843-308-9400
Hnd/Hawaiian Dredging A Joint Venture	Project Manager	614 Kapahulu Avenue Honolulu, HI 96815	808-735-3211
HNTB - Washington, DC	Mark Erdley	421 Seventh Street NW Washington, DC 20004	202-628-7525
Howard S. Wright Construction Co. (Fka Fletcher Wright, Inc.)	David or Norm, Estimating	501 East Lake Avenue East, Suite 100 Seattle, WA 98109-5451	206-447-7654
Hunt Building Corporation	Tim Bass, Purchasing Agent	4401 N. Mesa Suite 201 P.O. Box 12220 El Paso, TX 79902-1107	915-298-4256
J.A. Jones Management Services, Inc.	Steve Sullivan, Supplies Estimator	1333 H. Street, N.W. Suite 200 Washington, DC 20005	202-789-0770
J.P. Witherow Roofing Co Inc	Charlie Walters, General Manager	1001 Morena Blvd San Diego, CA 92110-3913	619-297-4701
James McHugh Construction Co	Michael Meagher, Vice President	1737 South Michigan Ave Chicago, IL 60616	312-986-8000
James N. Gray Company	Rick Troop	10 Quality Street Lexington, KY 40507-1760	859-281-5000
Johnson Controls World Service	Project Manager	7315 North Atlantic Ave Cape Canaveral, FL 32920	407-784-7320
Jowett, Incorporated	Fred Bellucci, Vice President	9106 Brandywine Road Clinton, MD 20735	301-868-2880
Kaplan/Mclaughlin/Diaz	Chet Wing, Project Manager	1011 Western Avenue Seattle, WA 98104	206-467-1004

COMPANY	CONTACT	ADDRESS	PHONE
Lincoln Builders, Inc.	Ken Henry, Vice President	1910 Farmerville Hwy., P.O. Box 400 Ruston, LA 71273-0400	318-255-3822
Martinez Amador Architects Inc	Jehush Martinez, Architectural Manager	8405 Pershing Drive Suite 201 Playa Del Rey, CA 90293	310-306-4708
Mason Technologies, Inc.	Project Manager	Msaap-Bldg. 9110 Stennis Space Center, MS 39529-7099	601-689-8605
Mcc Construction Corporation	Tam Bently, Proposals	5275 Dtc Parkway Englewood, CO 80111-2752	303-741-0404
Metric Construction Co., Inc.	Tom Miller, President	870 Hampshire Road Westlake, CA 91361	805-371-1222
Mid Eastern Builders, Inc.	Bruce Diggs, Chief Estimator	4016 Holland Blvd. P.O. Box 6748 Chesapeake, VA 23323	757-487-5858
Moffatt & Nichol Engineers	Dick Chan, Project Manager	3720 S. Susan Street, Suite 200 Santa Ana, CA 92704	714-979-2055
Nova/Staite(J/V)	Brenda Abel, Chief Estimator	P.O. Box 4050 Napa, CA 94558	707-257-3200
Pantech Construction Co	David Dawson, Project Manager/Estimator	4372 Lottsford Vista Road Lanham, MD 20706	301-731-7960
Phillips National, Inc.	Project Manager	215 S Highway 101 Ste 216 Solana Beach, CA 92075	619-755-7992
Pyro Installations Corporation	Project Manager	121 Meadow Street Hackensack, NJ 07601	973-790-5759
S. B. Ballard, Inc.	Mark Payne, Head Estimator	2828 Shipps Corner Road Virginia Beach, VA 23453	757-440-5555
Salerno/Livingston Architects	Rob Carrol, Project Manager	363 Fifth Avenue, 3rd Floor San Diego, CA 92101-6965	619-234-7471
Sato & Associates, Inc	Loren Lau, Project Manager	2046 South King Street Honolulu, HI 96826	808-955-4441
Sauer, Inc.	Project Manager	11223 Phillips Parkway Drive, East Jacksonville, Fl 32256-1574	904-262-6444
Shalom Baranes Associates, Pc	Shalom Baranes, President	3299 K Street, NW, Suite 400 Washington, DC 20007	202-342-2200
Shepley Bulfinch Richardson And Abbott	Jim Honeywell	40 Broad Street Boston, MA 02109	617-423-1700

COMPANY	CONTACT	ADDRESS	PHONE
Smithgroup, Inc	Patricia Healy	1825 I Street, N.W., Suite 250 Washington, DC 20006	202-842-2100
Solpac, Inc. Dba Soltek Pacific	Jim Summers, Design/Building Manager	2424 Congress St, Suite A San Diego,CA 92110-2888	619-296-6247
Structural Associates Inc	Dennis Weller, President	5903 Fisher Road East Syracuse, NY 13057	315-463-0001
Sundt Construction Inc	Randy Rusing, Chief Estimator	4101 E Irvington Road Tucson, AZ 85714	520-748-7555
T.B. Penick & Sons, Inc.	Paul Diaz, Chief of Operations	9747 Olson Drive San Diego, CA 92121	858-558-1800
Target Engineering, S.E.	Project Manager	P.O. Box 367 Saint Just, PR 00978	787-257-0413
The Environmental Company, Inc.	Jack Wilson	2496 Old Ivy Road, P.O. Box 5127 Charlottesville, VA 22905	434-295-4446
The Haskell Company	Tom Bold, Chief Estimator	111 Riverside Avenue Jacksonville, FL 32202	904-791-4500
Virtexco Corporation	Robert H. Wells, CEO & Chief Estimator	977 Norfolk Square Norfold, VA 23502	757-466-1114
Volmar Construction Inc	Fred Chan, Estimator	4400 Second Avenue Brooklyn, NY 11232	718-832-2444
W. G. Yates & Sons Construction Co	Dick Fitzgibbons, Chief Estimator	One Gully Avenue Philadelphia, MS 39350	601-656-5411
W.M. Jordan Company, Inc.	Gary Fintriss, Purchasing Agent	P.O. Box 1337 Newport News, VA 23601-0337	757-596-6341
Walsh Construction Co. Of Illinois	Walter Kuzabowski, Facilities Manager	929 W Adams St Chicago, IL 60607	312-563-5400
Whitesell-Green Inc/W.G. Yates & Sons Construction (Jv)	Roy Shannon, Project Manager	P.O. Box 5279 Biloxi, MS 39534	228-436-7788
Whiting-Turner Contracting Co	Joan Smith	300 East Joppa Road Baltimore, MD 21286	410-821-1100
Wilson Okamoto & Assoc. Inc.	Gary Okamoto, President	1907 S. Beretania Street, Suite 400 Honolulu, HI 96826	808-946-2277
Wimberly Allison Tong & Goo, Inc.	Dawn Metsumatsuyama	700 Bishop Street, Suite 1800 Honolulu, HI 96813	808-521-8888

COMPANY	CONTACT	ADDRESS	PHONE
Winzler & Kelly, Consulting Engrs.	Mark Solomon, Regional Manager	495 Tesconi Circle Santa Rosa, CA 95401	707-523-1010

Appendix 4: "Top 200+" Builders Population Contact List

COMPANY	CEO	ADDRESS	PHONE
Affordable Homes	Forrest Norman	P.O. Box 2130 Virginia Beach, VA 23450	757-306-9620
ALH Holdings	Shalom E. Lamm	7800 Belfort Pkwy. Suite 200 Jacksonville, FL 32256	904-279-9506
American Heritage Homes	Mark Ezzard	108 Park Place Blvd. Kissimmee, FL 34741	407-422-5508
American Standard Building Systems	James A. Lester	700 Commerce Ct. Martinsville, VA 24112	276-638-3991
American West Homes	Lawrence D. Canarelli	250 Pilot Rd. Suite 140 Las Vegas, NV 89119	702-736-6434
Ameri-Con Homes	Sandy Krulak	23611 Chagrin Blvd. Suite 103 Beachwood, OH 44122	216-831-3711
Anderson Homes	Larry W. Anderson	1420 S. Mills Ave. Suite A Lodi, CA 95241	209-367-7600
Apex Homes	Robert Nipple	247 U.S. Hwy. 522 N. Middleburg, PA 17842	570-837-2333
Arthur Rutenberg Homes	Arthur Rutenberg	13922 58th St., N. Clearwater, FL 33760	727-536-5900
Artistic Homes	Jerry Wade	44020 Tower Rd. S.W. Suite A Albuquerque, NM 87121	505-247-8400
Arvida/JMB Partners	James D. Motta	7900 Glades Rd. Boca Raton, FL 33434	561-479-1100
Ashton Woods Homes	Thomas C. Krobot	1405 Old Alabama Rd. Suite 120 Roswell, GA 30076	770-998-9663
Astoria Homes	Joel Laub	9555 Del Webb Blvd. Las Vegas, NV 89134	702-257-1188
Ausherman Homes	Marvin E. Ausherman	8031 Reichs Ford Rd. Frederick, MD 21704	301-620-4455
Bailey & Dutton	Craig Dutton	1641 Glen Oaks Dr. Reno, NV 89523	925-838-1460
Ball Homes	Ray Ball	3399 Tates Creek Rd. Lexington, KY 40502	859-268-1191

COMPANY	CEO	ADDRESS	PHONE
Barratt American	Stephen R. Reid	2035 Corte Del Nogal Suite 160 Carlsbad, CA 92009	760-431-0800
Bastian Homes	Eugene Bastian	1301 Colonial Club Dr. Harrisburg, PA 17112	717-671-0111
Beazer Homes USA	Ian J. McCarthy	5775 Peachtree Dunwoody Rd. Suite B-200 Atlanta, GA 30342	404-250-3420
Bill Clark Homes	William H. Clark	200 E. Arlington Blvd. Suite R Greenville, NC 27858	252-355-2000
Bob Ward Cos.	Robert C. Ward	2700 Philadelphia Rd. Edgewood, MD 21040	410-679-5000
Bowen Builders Group	Tom Rosser, VP Operations	P.O. Box 401 Buford, GA 30515	770-932-1332
Brayson Homes	L.E. Deavours	P.O. Box 1569 Duluth, GA 30096	678-475-0578
Bright Development	Carol Bright	1620 N. Carpenter Rd. Bldg. B Modesto, CA 95351	209-526-8242
Brighton Homes	Henry Broesche	13101 N.W. Fwy. Suite 312 Houston, TX 77040	713-460-0264
Brookfield Residential Group	Ian Cockwell	181 Bay St., BCE Pl. Suite 4400 Toronto, Ontario, Canada M5J2T3	416-369-8200
Brown Family Communities	David M. Brown	2164 E. Broadway Rd. Suite 300 Tempe, AZ 85282	480-921-1400
BT Building Systems	Harold Thomas	40 Oliver Terrace Shelton, CT 06484	203-225-9090
C.P. Morgan Communities	Charles P. Morgan	301 E. Carmel Dr. Suite E-300 Carmel, IN 46032	317-848-4040
California Homes	Pat Matthews	3202 W. March Ln. Stockton, CA 95219	209-951-5444
Capital Pacific Holdings	Hadi Makarechian	4100 MacArthur Blvd. Suite 200 Newport Beach, CA 92660	949-622-8400
Cardinal Homes	Bret Berneche	P.O. Box 10 Wylliesburg, VA 23976	434-735-8111
Carefree Homes	S.J. Thomas	1560 Goodyear Dr. El Paso, TX 79936	915-590-8511

COMPANY	CEO	ADDRESS	PHONE
Castle & Cooke	David H. Murdock	10900 Wilshire Blvd. Suite 1600 Los Angeles, CA 90024	310-208-3636
Cavalier Homes	David Roberson	32 Wilson Blvd., Suite 100 P.O. Box 450 Addison, AL 35540	256-747-9800
Cavco	Joe Stegmayer	1001 N. Central Ave. Suite 800 Phoenix, AZ 85004	602-256-6263
Centerline Homes	Craig Perry	12534 Wiles Rd. Coral Springs, FL 33076	954-344-8040
Centex Corp.	Laurence E. Hirsch	2728 N. Harwood Dallas, TX 75201	214-981-5000
Century Homebuilders	Sergio Pino	7270 N.W. 12th St. Suite 410 Miami, FL 33126	305-599-8100
Century Vintage Homes	John Pavelak	1535 South D St. San Bernardino, CA 92408	909-381-6007
Champion Enterprises	Walter R. Young	2701 Cambridge Ct. Suite 300 Auburn Hills, MI 48326	248-340-9090
Choice Homes	Stephen T. Wall	1600 E. Lamar Blvd. Suite 340 Arlington, TX 76011	817-652-5100
Classic Homes	Jeff Smith	6385 Corporate Dr. Suite 200 Colorado Springs, CO 80919	719-592-9333
Clayton Homes	Kevin Clayton	5000 Clayton Rd. Maryville, TN 37802	865-380-3000
Coachmen Housing and Building Systems Group	John T. Trant	2831 Dexter Dr. Elkhart, IN 46515	574-262-0123
Colony Homes	Thomas L. Bradbury	110 Londonderry Ct. Suite 136 Woodstock, GA 30188	770-928-0092
Comstock Homes	Christopher Clemente	1313 Dolley Madison Blvd. Suite 302 McLean, VA 22101	703-883-1700
Concord Homes	Wayne Moretti	1540 E. Dundee Rd. Suite 350 Palatine, IL 60074	847-776-0350
Concordia Homes	O. Randolph Hall Jr.	980 American Pacific Suite 100 Henderson, NV 89014	702-434-5200
Craftmark Group	Kenneth G. Malm	6820 Elm St. McLean, VA 22101	703-734-9855

COMPANY	CEO	ADDRESS	PHONE
Crestline Homes	Joe D. Manis	5800 Crestline Rd. Laurinburg, NC 28351	910-276-0195
Crossmann Communities	John B. Scheumann	9210 N. Meridian St. Indianapolis, IN 46260	317-843-9514
Crosswinds Communities	Bernard Glieberman	41050 Vincenti Ct. Novi, MI 48375	248-615-1313
D.R. Horton	Donald J. Tomnitz	1901 Ascension Blvd. Suite 100 Arlington, TX 76006	817-856-8200
Darling Homes	William C. Darling	2500 Legacy Dr. Suite 100 Frisco, TX 75034	972-624-4100
David Cutler Group	David Cutler	5 Sentry Pkwy. Blue Bell, PA 19422	610-940-9800
David Weekley Homes	David Weekley	1111 N. Post Oak Rd. Houston, TX 77055	713-963-0500
Davis Homes	Charles R. Davis	3755 E. 82nd St. Suite 120 Indianapolis, IN 46240	317-595-2800
Dominion Homes	Douglas G. Borror	5501 Frantz Rd. Dublin, OH 43017	614-761-6000
Don Simon Homes	David Simon	2800 Royal Ave. Madison, WI 53713	608-223-2626
Dunmore Homes	Sidney B. Dunmore	2150 Professional Dr. Suite 150 Roseville, CA 95661	916-771-7500
Dura Builders	Paul Shoopman	5740 Decatur Blvd. Indianapolis, IN 46241	317-821-8100
Dynamic Homes	Scott Lindemann	525 Roosevelt Ave. Detroit Lakes, MN 56502	218-847-2611
Eastwood Homes	Joe Stewart	2857 Westport Rd. Charlotte, NC 28208	864-286-9670
Elliott Homes	Harry C. Elliott III	2390 E. Bidwell St. Folsom, CA 95630	916-984-1300
Excel Homes	Ed Langley	Box 683A RR 2 Liverpool, PA 17045	717-444-3395
Fall Creek Housing	Kenneth Geljack Sr.	53850 Fall Creek Way Elkhart, IN 46514	574-523-1444

COMPANY	CEO	ADDRESS	PHONE
Fieldstone Communities	Frank S. Foster	14 Corporate Plaza Newport Beach, CA 92660	949-640-9090
First Home Builders of Florida	Patrick Logue	2503 Del Prado Blvd. Suite 300 Cape Coral, FL 33904	941-458-8000
Fischer Homes	Henry Fischer	2670 Chancellor Dr. Crestview Hills, KY 41017	859-341-4709
Fleetwood Enterprises	Nelson W. Potter	P.O. Box 7638 Riverside, CA 92513	909-351-3500
Florsheim Homes	David Florsheim	1701 W. March Ln. Suite D Stockton, CA 95207	209-473-1106
Four Seasons Housing	Austin Baidas	11333 CR2 P.O. Box 630 Middlebury, IN 46540	219-825-9999
Frontier Land Cos.	Thomas P. Doucette	3247 W. March Ln. Suite 220 Stockton, CA 95219	209-957-8112
Fulton Homes	Douglas Fulton	9140 S. Kyrene St. Suite 202 Tempe, AZ 85284	480-753-6789
Fuqua Homes	Phillip R. Daniels	7100 S. Cooper St. Arlington, TX 76001	817-465-3211
G.L. Homes of Florida	Itchko Ezratti	1401 University Dr., Suite 200 Coral Springs, FL 33076	954-753-1730
Gateway Homes	Tom Walker	10255 Richmond Ave. Suite 400 Houston, TX 77042	713-622-3737
Gehan Homes	Glenn Gehan	1101 N. Union Bower Rd. Suite 160 Irving, TX 75061	972-579-5066
Gemcraft Homes	Bill Luther	P.O. Box 647 Fallston, MD 21047	410-893-8458
Genesis Homes	Roger Lasater	2701 Cambridge Ct. Suite 320 Auburn Hills, MI 48326	248-340-9090
Giles Industries	Alan Neely	405 S. Broad St., New Tazewell, TN 37825	423-626-7243
Grand Homes	Stephen H. Brooks	8350 N. Central Expwy. Suite 900 Dallas, TX 75206	214-750-6528
Habitat for Humanity International	Millard Fuller	121 Habitat St. Americus, GA	229-924-6935

COMPANY	CEO	ADDRESS	PHONE
Hacienda Builders	David Cohen	4250 N. Drinkwater Blvd. Suite 360 Scotsdale, AZ 85251	480-945-4200
Hamlet Homes Corp.	John Aldous	470 East 3900 S. Suite 200 Salt Lake City, UT 84107	801-281-2223
Hammonds Homes	Ron Hammonds	7171 Hwy. 6 N. Suite 201 Houston, TX 77095	281-463-6343
Harkins Builders	Blasé Cooke	2201 Warwick Way Marriottsville, MD 21104	410-750-2600
Hayden Homes	Hayden H. Watson	2622 S.W. Glacier Pl. Suite 110 Redmond, OR 97756	541-923-6607
Hedgewood Properties	Pam Sessions	5930 Post Rd. Cumming, GA 30040	770-889-3667
Highland Homes	Rodger Sanders	12850 Hillcrest Suite 200 Dallas, TX 75230	972-387-7905
Hills Communities	Stephen Guttman	7420 Montgomery Rd. Cincinnati, OH 45236	513-984-0300
Hi-Tech Housing	Gregory F. Pizza	19319 CR8 Bristol, IN 46507	574-848-5593
Holiday Builders	Richard W. Hawkes	2293 W. Eau Gallie Blvd. Melbourne, FL 32935	321-259-3130
Holly Park	John Guequierre	51700 Lovejoy Dr. Middlebury, IN 46540	574-825-3700
Horton Homes	N.D. Horton Jr.	P.O. Box 4410 101 Industrial Blvd. Eatonton, GA 31024	706-485-8506
Hubble Homes	Don Hubble	701 S. Allen St. Suite 104 Meridian, ID 83642	208-466-3600
Hunt Building Corp.	Woody L. Hunt	4401 N. Mesa St. Suite 201 El Paso, TX 79902	915-533-1122
Inland Homes	Jim Clark	8401 JR Manor Dr. Tampa, FL 33634	813-886-8051
Intervest Construction	Mori Hosseini	2359 Beville Rd. Daytona Beach, FL 32119	386-788-0820
Ivanhoe Huntley Homes	Gary Shapiro	7001 Orchard Lake Rd. Suite 200 West Bloomfield, MI 48322	248-851-5800

COMPANY	CEO	ADDRESS	PHONE
Ivory Homes	Clark D. Ivory	970 Woodoak Ln. Salt Lake City, UT 84117	801-268-0700
J.T.S. Communities	Jack T. Sweigart	3434 Marconi Ave. Sacramento, CA 95821	916-487-3434
Jacobsen Manufacturing	W.R. Jacobsen	P.O. Box 368 600 Packard Ct. Safety Harbor, FL 34695	727-726-1138
Jim Walter Homes	Michael M. Roberts	4211 W. Boy Scout Blvd. Tampa, FL 33607	813-871-4611
John Mourier Construction	John L. Mourier III	1830 Vernon Street Suite 9 Roseville, CA 95678	916-782-8879
John Wieland Homes and Neighborhoods	John Wieland	1950 Sullivan Rd. Atlanta, GA 30337	770-996-1400
K. Hovnanian Enterprises	Ara K. Hovnanian	10 Hwy. 35 P.O. Box 500 Red Bank, NJ 07701	732-747-7800
Kalian Corp.	Mazin A. Kalian	225 Hwy. 35 Red Bank, NJ 07701	732-741-0054
KB Home	Bruce Karatz	10990 Wilshire Blvd. Los Angeles, CA 90024	310-231-4000
Keller Homes	David A. Keller	7222 Commerce Center Dr. Suite 212 Colorado Springs, CO 80919	719-528-6977
Kenar Homes	Ken Struck	1904 Wright Blvd. Schaumburg, IL 60193	847-352-0100
Kenco Homes	Kent Roessler	13736 Johnson St. N.E. Ham Lake, MN 55304	763-757-4052
Kennedy Group of Cos.	William W. Kennedy	1051 E. Main St. Suite 110 Dundee, IL 60118	847-844-8500
Key-Land Homes	Gary Horkey	17021 Fish Point Rd. S.E. Prior Lake, MN 55372	952-440-9400
KFarrelli	Mark Kaufman	16000 Memorial Dr. Suite 250 Houston, TX 77079	281-558-6800
Kimball Hill Homes	David K. Hill	5999 New Wilke Rd. Suite 504 Rolling Meadows, IL 60008	847-364-7300
Kirk Homes	John Carroll	201 Juniper Circle Streamwood, IL 60101	630-830-8300

COMPANY	CEO	ADDRESS	PHONE
Kyle Carter Homes	Kyle Carter	3851 Fruitvale Ave. Bakersfield, CA 93308	661-399-0239
Lakewood Homes	Buz Hoffman	2500 W. Higgins Rd. Suite 1250 Hoffman Estates, IL 60195	847-884-8800
Landstar Homes	Rodolfo Stern	550 Biltmore Way Suite 1110 Coral Gables, FL 33134	305-461-2440
Lennar Corp.	Stuart A. Miller	700 N.W. 107th Ave. Miami, FL 33172	305-559-4000
Levitt and Sons	Elliott Wiener	7777 Glades Rd. Suite 410 Boca Raton, FL 33434	561-482-5100
Liberty Homes	Edward J. Hussey	P.O. Box 35 1101 Eisenhower Dr. N. Goshen, IN 46527	219-533-0431
Life Forms	Mark Alvis	3400 Research Forest Dr. Suite B-8 The Woodlands, TX 77381	281-367-3248
Longford Homes	John Murtagh	3077 E. Warm Springs Rd. Las Vegas, NV 89120	702-454-5300
Lowder New Homes	Alan S. Farrior	2000 Interstate Park Dr. Suite 401 Montgomery, AL 36109	334-270-6516
M.D.C. Holdings	Larry A. Mizel	3600 S. Yosemite St. Suite 900 Denver, CO 80237	303-773-1100
M.W. Johnson Construction	M. William Johnson	17645 Juniper Path Suite 100 Lakeville, MN 55044	952-892-5200
M/I Schottenstein Homes	Irving E. Schottenstein	3 Easton Oval Suite 500 Columbus OH 43219	614-418-8000
Manufactured Housing Enterprises	James L. Newman Sr.	09302 SR #6 Bryan, OH 43506	419-636-4511
Maracay Homes Arizona	Dave Bessey	15160 N. Hayden Rd. Suite 200 Scotsdale, AZ 85260	480-346-5202
Marrano/Marc Equity Corp.	Patrick Marrano	2730 Transit Rd. Buffalo, NY 14224	716-675-1200
Masonry Homes	Martin K. P. Hill	4219 Hanover Pike Manchester, MD 21102	410-239-8330
Mayer Homes	J. Randall Mayer	755 S. New Balles Suite 210 St. Louis, MO 63141	314-997-2300

COMPANY	CEO	ADDRESS	PHONE
MBK Homes	Stefan Marhowitz	175 Technology Dr. Irvine, CA 92618	949-789-8300
McBride & Son Enterprises	Richard T. Sullivan Jr.	1 McBride & Son Center Dr. Chesterfield, MO 63005	636-537-2000
MCL Cos.	Daniel E. McLean	455 E. Illinois St. Suite 565 Chicago, IL 60611	312-321-8900
MCZ Development	Michael Lerner	1555 N. Sheffield Ave. Chicago, IL 60622	312-573-1122
MDC Homes	Keith McSwain	11525 Park Woods Cir. Alpharetta, GA 30005	770-206-9100
Medallion Homes	James W. Bastoni	6929 Camp Bullis Rd. San Antonio, TX 78256	210-494-2555
Mercedes Homes	Keith Buescher	6767 N. Wickham Suite 500 Melbourne, FL 32940	321-259-6972
Meridian Homes of Georgia	Darrell McWaters	P.O. Box 40 Loganville, GA 30052	770-466-1001
Meritage Corp.	John R. Landon	4050 W. Park Blvd. Plano, TX 75093	972-612-8085
MHI	Frank McGuyer	7676 Woodway Suite 104 Houston, TX 77063	713-952-6767
Miller and Smith	Alvin D. Hall	1568 Spring Hill Rd. Suite 400 McLean, VA 22102	703-821-2500
MJC Cos.	Michael A. Chirco	46600 Romeo Plank Rd. Suite 5 Macomn, MI 48044	586-263-1203
Montalbano Homes	Anthony Montalbano	2208 Midwest Rd. Oak Brook, IL 60523	630-571-8877
Morrison Homes	Stewart M. Cline	3700 Mansell Rd. Suite 300 Alpharetta, GA 30022	770-998-9044
Muncy Homes	Thomas M. Saltsgiver	1567 Pa. Hwy. 442 P.O. Box 246 Muncy, PA 17756	570-546-5444
Nationwide Homes	Ronald C. Evans	P.O. Box 5511 1100 Rives Rd, Martinsville, VA 24115	276-632-7100
NCC Technology	William Linder	233 W. Market St. Newark, NJ 07103	973-639-7044

COMPANY	CEO	ADDRESS	PHONE
Neumann Homes	Kenneth P. Neumann	4355 Weaver Pkwy. Warrenville, IL 60555	630-281-2000
New Era Building Systems	Elliot J. Fabri	P.O. Box 269 451 Southern Ave. Strattanville, PA 16258	800-678-5581
NVR	Dwight C. Schar	7601 Lewinsville Rd. Suite 300 McLean, VA 22102	703-761-2000
Oakwood Homes	Myles Standish	7800 McCloud Rd. Greensboro, NC 27425	336-664-2400
Ole South Properties	John D. Floyd	275 Robert Rose Dr. Murfreesboro, TN 37129	615-896-0019
Orleans Homebuilders	Jeffrey P. Orleans	3333 Street Rd., One Greenwood Sq. Suite 101 Bensalem, PA 19020	215-245-7500
Pacific Bay Homes	John Markley	4041 MacArthur Blvd. Suite 500 Newport Beach, CA 92660	949-440-7200
Pacific Century Homes	William W. Lo	40925 County Center Dr. Suite 110 Ternecula, CA 92591	909-719-1464
Palm Harbor Homes	Larry Keener	15303 Dallas Pkwy. Suite 800 Addison, TX 75001	972-991-2422
Park Square Homes	Steve O'Dowd	5200 Vineland Rd. Suite 200 Orlando, FL 32811	407-529-3000
Pasquinelli Construction Co.	Bruno A. Pasquinelli	905 W. 175th St. Suite 300 Homewood, IL 60430	708-957-3405
Patriot Homes	Samuel V. Weidner Sr.	307 S. Main St. Suite 200 Elkhart, IN 46516	574-524-8600
Peachtree Residential Properties	David J. Borreson	7380 McGinnis Ferry Rd. Suwanee, GA 30024	770-622-2522
Pembroke Enterprises	Richard E. Olivieri	4425 Corporation Ln. Suite 400 Virginia Beach, VA 23462	757-490-3141
Penn Lyon Homes	Roger Lyons	101 Airport Rd. P.O. Box 27 Selinsgrove, PA 17870	570-374-4004
Perry Homes, a Joint Venture	Bob Perry	P.O. Box 34306 Houston, TX 77234	713-947-1750
Plaster Development Co./Signature Homes	Richard Plaster	801 S. Rancho Dr. Suite E-4 Las Vegas, NV 89106	702-385-5031

COMPANY	CEO	ADDRESS	PHONE
Polygon Northwest Co.	Jeffery D. Gow	11624 S.E. 5th St. Suite 200 Bellevue, WA 98005	425-586-7700
Premier Design Homes	Alejandro Robles	11030 N. Kendall Dr. Miami, FL 33176	305-271-6997
Pringle Development	John A. Pringle	26600 Ace Ave. Leesburg, FL 34748	352-365-2303
Pulte Corp.	Mark J. O'Brien	33 Bloomfield Hills Pkwy. Suite 200 Bloomfield, Hills, MI 48304	248-433-4597
R-Anell Custom Homes	Dennis L. Jones	P.O. Box 428 Denver, NC 28037	704-483-5511
Realen Homes	Vincent G. DeLuca	1040 Stony Hill Rd. Suite 100 Yardley, PA 19067	215-497-0600
Realty Development Corp.	Marc S. Pollack	5555 Glenridge Connector Suite 700 Atlanta, GA 30342	404-459-6115
Ritz-Craft	Paul D. John	P.O. Box 70 15 Industrial Park Rd. Mifflinburg, PA 17844	570-966-1053
Robson Communities	Edward J. Robson	9532 E. Riggs Rd. Sun Lakes, AZ 85248	480-895-9200
Rochester Homes	Kenny Anderson	1345 N. Lucas St. Rochester, IN 46975	800-860-4554
Royce Homes	John Speer	7850 N. Sam Houston Pkwy. W. Houston, TX 77064	281-440-5091
Ryan Building Group	William J. Ryan	945 N. Plum Grove Rd. Chicago, IL 60173	847-995-8700
Ryder Homes	Jay Ryder	1425 Treat Blvd. Walnut Creek, CA 94596	925-937-4373
Salisbury Development	Rick Salisbury	494 W. 1300 N., Springville, UT 84663	801-491-9091
Schuler Homes	James K. Schuler	400 Continental Blvd. Suite 100 El Sugundo, CA 90245	310-648-7200
SEDA Construction Co.	John A. Semanik	2120 Corporate Sq. Blvd. Suite 3 Jacksonville, FL 32216	904-724-7800
Seeno Homes	Albert Seeno Jr.	4021 Port Chicago Hwy. Concord, CA 94524	925-671-7711

COMPANY	CEO	ADDRESS	PHONE
Sharp Residential Builders & Developers	Tom Sharp	4080 McGinnis Ferry Rd. Suite 701 Alpharetta, GA 30005	770-518-4896
Shea Homes	Bert Selva	655 Brea Canyon Rd. Walnut, CA 91789	909-594-0901
Shugart Enterprises	Grover F. Shugart, Jr.	3015 Maplewood Ave. Winston-Salem, N.C. 27103	336-765-9661
Signature Building Systems	Victor DePhillips	1004 Springbrook Ave. Moosic, PA 18507	570-774-1000
Simpson Housing Limited Partnership	Donald A. Simpson	3201 S. Tamarac Dr. Suite 200 Denver, CO 80231	303-283-4190
Sivage-Thomas Homes	Michael D. Sivage	7445 Pan American Fwy., N.E. Albuquerque, NM 87109	505-341-6800
Skyline Corp.	Arthur J. Decio	2520 By-Pass Rd. Elkhart, IN 46515	219-294-6521
Southern Energy Homes	Wendell L. Batchelor	P.O. Box 390 Addison, AL 35540	256-747-8589
Sovereign Homes	Rick Strauss	2485 E. Southlake Blvd. Suite 160 Southlake, TX 76092	817-329-8829
Spectrum Skanska	Mitchell C. Hochberg	115 Stevens Ave. Valhalla, NY 10595	914-773-1200
St. Lawrence Homes	F. Robert Ohmann	7200 Falls of Neuse Rd. Raleigh, NC 27615	919-676-8980
Standard Pacific Corp.	Stephen J. Scarborough	15326 Alton Pkwy. Irvine, CA 92618	949-789-1600
Stanpark Construction Co.	David M. Carver	3320 N. Buffalo Dr. Suite 207 Las Vegas, NV 89129	702-396-3887
Stratford Homes	Ron McCaslin	P.O. Box 37 Stratford, WI 54484	715-687-3133
Suarez Housing Corp.	Roger J. Suarez	9950 Princess Palm Ave. Tampa, FL 33619	813-664-1100
Syncon Homes	Brian Hanly	1380 Lead Hill Blvd. Suite 201 Roseville, CA 95661	916-772-5221
Taylor Building Corp. of America	Eric W. Taylor	One Riverfront Plaza Suite 906 Louisville, KY 40202	502-582-1800

COMPANY	CEO	ADDRESS	PHONE
Taylor Woodrow	John R. Peshkin	8430 Enterprise Cir. Suite 100 Bradenton, FL 34202	941-554-2000
Taylor-Morley Homes	Mark Morley	17107 Chesterfield Airport Rd. Chesterfield, MO 63005	314-434-9000
Technical Olympic USA	Anthony B. Mon	4000 Hollywood Blvd. Suite 500 N Hollywood, FL 33021	954-364-4000
The Bozzuto Group	Thomas S. Bozzuto	6401 Golden Triangle Dr. Suite 200 Greenbelt, MD 20770	301-220-0100
The Corky McMillin Cos.	Corky McMillin	2727 Hoover Ave. National City, CA 91950	619-477-4117
The Drees Co.	David G. Drees	211 Grandview Dr. Fort Mitchell, Ky. 41017	859-578-4200
The Erpenbeck Co.	Bill Erpenbeck	130 Dudley Rd. Edgewood, KY 41017	859-331-8090
The Estridge Cos.	Paul Estridge Jr.	1041 W. Main St. Carmel, IN 46032	317-846-7311
The Forecast Group	James P. Previti	10670 Civic Center Dr. Rancho Cucamonga, CA 91730	909-987-7788
The Fortress Group	George Yeonas	1650 Tysons Blvd. Suite 600 McLean, VA 22102	703-442-4545
The IDI Group Cos.	Giuseppe Cecchi	1700 N. Moore St. Suite 2020 Arlington, VA 22209	703-558-7300
The Jones Co.	Robert Jones	16640 Chesterfield Grove Rd. Suite 200 Chesterfield, MO 63005	636-537-7000
The Knight Group	Jay Knight	9497 Thornton Blvd. Jonesboro, GA 30236	770-471-4751
The Mitchell Co.	John B. Saint	P.O. Box 160306 Mobile, AL 36616	251-380-2929
The Oberer Cos.	George R. Oberer Jr.	4324 Webster St. Dayton, OH 45414	937-278-0851
The Quaker Group	Stephen R. Shilling	598 Bethlehem Pike Montgomeryville, PA 18936	215-822-9373
The Rottlund Co.	David H. Rotter	3065 Centre Pointe Dr. Roseville, MN 55113	651-638-0500

COMPANY	CEO	ADDRESS	PHONE
The Ryland Group	R. Chad Dreier	24025 Park Sorrento Suite 400 Calabasas, CA 91302	818-223-7500
The Thrush Cos.	David Chase	357 W. Chicago Ave. Chicago, IL 60610	312-787-5580
The Villages of Lake Sumter	H. Gary Morse	1100 Main St. The Villages, FL 32159	352-753-2270
TK Constructors	Mark Thurston	5141 W. Hessler Rd. Muncie, IN 47304	765-282-5500
Toll Brothers	Robert I. Toll	3103 Philmont Ave. Huntingdon Valley, PA 19006	215-938-8000
Town & Country Homes	Thomas E. Ryan	1806 S. Highland Ave. Lombard, IL 60148	630-953-2222
Transeastern Properties	Arthur Falcone	3300 University Dr. Coral Springs, FL 33065	954-346-9700
Trend Homes	Reed Porter	2020 N. Arizona Ave. Suite G-62 Chandler, AZ 85225	480-821-8000
Unibilt Industries	Douglas Scholz	P.O. Box 373 4671 Poplar Creek Rd. Vandalia, OH 45377	937-890-7570
Venture Homes	Robert C. White	1580 Terrell Mill Rd. Marietta, GA 30067	770-955-8300
Village Homes of Colorado	John E. Osborn	6 W. Dry Creek Circle Littleton, CO 80120	303-795-1976
Warmington Homes California	Timothy P. Hogan	3090 Pullman St. Costa Mesa, CA 92626	714-557-5511
WCI Communities	Alfred Hoffman Jr.	24301 Walden Center Dr. Bonita Sprints, FL 34134	941-498-8691
Wensmann Homes	Herbert Wensmann	1895 Plaza Dr. Suite 200 Eagan, MN 55122	651-905-3709
Westchester Modular Homes	Charles Hatcher	30 Reagans Mill Rd. Wingdale, NY 12594	845-832-9400
Westfield Homes USA	Roger B. Gatewood	4300 W. Cypress St. Suite 980 Tampa. FL 33607	813-874-9872
Weyerhaeuser Real Estate Co.	Dan Fulton	E. Campus 3, 3B9 P.O. Box 9777 Federal Way, WA 98063	253-924-3034

COMPANY	CEO	ADDRESS	PHONE
Whittaker Builders	Greg Whittaker	355 Mid Rivers Mall Dr. Suite A St. Peters, MO 63376	636-970-1511
Wick Homes	Jeff F. Wick	400 Walter Rd. P.O. Box 188 Mazomanie, WI 53560	608-795-2261
William Lyon Homes	William Lyon	4490 Von Karman Ave. Newport Beach, CA 92660	949-833-3600
Windward Homes	Chad Horne	5402 Beaumont Center Blvd. Tampa, FL 33634	813-885-7744
Wiseman-Hughes Enterprises	James Wiseman	975 E. 22nd St. Wheaton, IL 60187	630-653-0500
WL Homes	H. Lawrence Webb	895 Dove St. Suite 200 Newport Beach, CA 92660	949-265-2400
Woodside Group	Ezra K. Nilson	39 E. Eagleridge Suite 102 North Salt Lake, UT 84054	801-299-6700

Appendix 5: Distributor/Retailer Population Contact List

D/R	Company	Contact	Address	Phone
D	A.W. Hastings & Co. Inc.	Keenan Burns, General Buyer	2 Pearson Way Enfield, CT 06082-2654	860 745-2424
D	ABC Supply Co. Inc.	Brent Fox, Director Purchasing Roofing	PO Box 838 Beloit, WI 53512-0838	608 362-7777
D	Ace Hardware Corp.	Wayne Wiggleton, VP Lumber	2200 Kensington Ct Oak Brook, IL 60523-2100	630 990-6600
D	Aetna Plywood Inc.	John Chlebek, Buyer Lumber	104 S Wynstone Park Dr North Barrington, IL 60010-6967	847 382-5500
D	Alamo Forest Products	Daryl Woody, VP Operations	PO Box 17258 San Antonio, TX 78217-0258	210 352-1333
D	ALL Roofing & Building Materials Corp.	James Lessel, VP Purchasing	3645 Long Beach Blvd Long Beach, CA 90807-4018	562 595-7531
D	All-Coast Forest Products Inc.	Bill Sharp, VP Purchasing	PO Box 4120 Chino, CA 91708-4120	909 627-8551
D	Allied Building Products Corp.	David Wightman, Buyer Lumber	PO Box 511 East Rutherford, NJ 07073-0511	201 507-8400
D	Allied Building Stores Inc.	Billy Fuller, Merchandise Manager Windows & Doors	PO Box 8030 Monroe, LA 71211-8030	318 343-7200
D	Allied Plywood Corp.	Charles Hammer, Director Purchasing	6189 Grovedale Ct Alexandria, VA 22310-2553	703 922-2805
D	Amerhart Ltd.	Jeff Kocken, Buyer Lumber	PO Box 10097 Green Bay, WI 54307-0097	920 494-4744
D	American International Forest Products Inc.	Steve Culbertson, Buyer Lumber	PO Box 4166 Portland, OR 97208-4166	503 641-1611
D	American Paneling Plywood & Lumber Inc.	Randy Bordelon, General Buyer	PO Box 367 Port Neches, TX 77651-0367	409 722-9311
D	Arling Lumber Inc.	P.J. Arling, Buyer Lumber	PO Box 58359 Cincinnati, OH 45258-0359	513 451-5700
D	Associated Building Material Dist. of America Inc.	Larry Baugh, General Buyer	7501 E McCormick Pkwy Ste 206N Scottsdale, AZ 85258-3471	602 998-0696
D	Atlanta Hardwood Corp.	Dan Caldwell, General Buyer	5596 Riverview Rd SE Mableton, GA 30126-2914	404 792-2290

D/R	Company	Contact	Address	Phone
D	Atlantic Plywood Corp.	Jon Swennes, Buyer Lumber	PO Box 2805 Woburn, MA 01888-1405	781 933-1932
D	Babcock Lumber Co.	Tony Stillitano, Buyer Lumber	PO Box 8348 Pittsburgh, PA 15218-0348	412 351-3515
D	Baer Supply Co. Inc.	Stan Rzasa, Director Purchasing	909 Forest Edge Dr Vernon Hills, IL 60061-3149	847 913-2237
D	Belco Inc.	Stu Bettesworth, Director Purchasing	PO Box 98510 Tacoma, WA 98498-0510	253 584-2264
D	Best Distributing Co. Inc.	Marcellus J. Best Jr, Buyer Windows & Doors	PO Box 128 Goldsboro, NC 27533-0128	919 735-1651
D	Birmingham International Forest Products Inc.	Pat O'Connor, Buyer Lumber	PO Box 360448 Birmingham, AL 35236-0448	205 988-3102
D	Black Millwork Co. Inc.	Dennis Semsey, General Buyer	PO Box 27 Allendal, NJ 07401-0027	201 934-0100
D	Blish-Mize Co.	Steve Downs, VP Purchasing	PO Box 249 Atchison, KS 66002-0249	913 367-1250
D	Bloch Lumber Co.	Ashley Boeckholt, Buyer Lumber	2 N Riverside Plz Ste 2300 Chicago, IL 60606-2601	312 466-4500
D	Boddington Lumber Co.	Woody McWilliams, Buyer Windows & Doors	PO Box 7590 Colorado Springs, CO 80933-7590	719 528-6000
D	Boise Cascade Corp.	Frank Elfering, General Buyer	PO Box 50 Boise, ID 83728-0050	208 384-6366
D	Bradco Supply Corp.	Larry Gelber, Buyer Lumber	13 Production Way Avenel, NJ 07001-1628	732 382-3400
D	Buckeye Pacific Corp.	Larry Cole, Buyer Lumber	PO Box 168 Portland, OR 97207-0168	503 228-3330
D	Builder Marts of America	Gregg Jaques, Director Purchasing	PO Box 47 Greenville, SC 29602-0047	864 297-6101
D	Building Material Wholesalers Inc.	Bruce Disney, Buyer Lumber	PO Box 606 Galt, CA 95632-0606	209 745-3001
D	Building Products Inc.	Tom Krejchi, General Buyer	PO Box 1390 Watertown, SD 57201-6390	605 886-3495
D	Cameron Ashley Building Products Inc.	Fred Franklin, Buyer Lumber	11651 Plano Rd Ste 100 Dallas, TX 75243-5256	214 860-5100

D/R	Company	Contact	Address	Phone
D	Canton Lumber Co.	Steve From, Director Purchasing	PO Box 9328 Minneapolis, MN 55440-9328	612 425-1400
D	Capital Lumber Co.	Mark Lofland, Director Purchasing	2111 E Highland Ave Ste 155 Phoenix, AZ 85016-4757	602 381-0709
D	Carolina Builders (Hopson Building)	Chris Ball, Buyer Lumber	PO Box 6669 Marietta, GA 30065-0669	770 578-2400
D	Cascade Empire Corp.	Craig Rohlfing, General Buyer	PO Box 2770 Portland, OR 97208-2770	503 636-5666
D	Cedar Creek Wholesale Inc.	Dave Bond, VP	PO Box 1900 Brokern Arrow, OK 74013-1900	918 258-9688
D	Century Maintenance Supply Inc.	Dave Ryle, Director Purchasing	10050 Cash Rd Stafford, TX 77477-4407	281 208-2600
D	Commonwealth Wood Preservers Inc.	James Halstead, Buyer Lumber	5604 City Line Rd Hampton, VA 23661-1223	757 247-3622
D	Continental Hardwood Co.	Lisa Johnson, CEO	4800 S 188th St Seattle, WA 98188-4675	206 242-3300
D	Continental Timber Co. Inc.	Ron Watkins, Director Purchasing	PO Box 316 Valley Center, KS 67147-0316	316 755-2361
D	Coos Head Lumber & Plywood Co. Inc.	Ron O. McCormick, General Buyer	PO Box 750 Coos Bay, OR 97420-0143	541 267-2193
D	D.W. Distribution Inc.	Tim Dunlap, Buyer Lumber	PO Box 271023 Dallas, TX 75227-1023	214 381-2200
D	Dairyman's Supply Co. Inc.	David Fowler, Buyer Lumber	PO Box 528 Mayfield, KY 42066-0528	502 247-5642
D	Dealers Choice	Larry Gartner, General Buyer	2200 Cook Dr Atlanta, GA 30340-3133	770 246-3434
D	Design House Inc.	Sol Malka, VP Merchandising	PO Box 1001 Germantown, WI 53022-8201	414 255-1970
D	Diablo Timber Co.	Rick Rosa, General Buyer	PO Box 3690 Napa, CA 94558-0368	707 252-6142
D	Diamond Hill Plywood Co.	Jack Salway, VP Purchasing	PO Box 529 Darlington, SC 29540-0529	843 393-2803
D	Distribution America	Paul McNally, Merchandise Manager Lumber	2700 S River Rd Ste 300 Des Plaines, IL 60018-4100	847 296-7000

D/R	Company	Contact	Address	Phone
D	Dixie Plywood & Lumber Co.	Randy Collins, General Buyer	PO Box 2328 Savannah, GA 31402-2328	912 236-3385
D	Do it Best Corp.	Dave Cole, VP Purchasing	PO Box 868 Fort Wayne, IN 46801-0868	219 748-5300
D	East Coast Millwork Wholesalers Inc.	Art Groce, General Buyer	PO Box 130 North Wilkesboro, NC 28659-0130	336 667-5976
D	Eastex Forest Products	Bobbie Schil, Buyer Lumber	5429 Hartwick Rd Houston, TX 77095-2255	281 449-1071
D	Empire Wholesale Lumber Co.	Bill Kramer, Buyer Lumber	PO Box 249 Akron, OH 44309-0249	330 434-4545
D	ENAP Inc.	Donald Parsons, Buyer Lumber	121 Executive Dr New Windsor, NY 12553-5509	914 564-4900
D	Famous Supply Co.	Marc Blaushild, VP Operations	PO Box 1889 Akron, OH 44309-1889	330 762-9621
D	Fargo Glass & Paint Co.	Dennis Dunlop, Buyer Windows & Doors	PO Box 3107 Fargo, ND 58108-3107	701 235-4441
D	Fingerle Lumber Co.	Mark Fingerle, Buyer Lumber	PO Box 1167 Ann Arbor, MI 48106-1167	734 663-0581
D	Florence Corp.	Damien Carey, Buyer Lumber	1647 E Jericho Tpke Huntington, NY 11743-5797	516 499-6200
D	Forest City Trading Group Inc.	John W. Judy, General Buyer	PO Box 4209 Portland, OR 97208-4209	503 246-8500
D	Furman Lumber Inc.	Jim McCarthy, Buyer Lumber	PO Box 130 Nutting Lake, MA 01865-0130	978 670-3800
D	Futter Lumber Corp.	Bernard Futter, Director Purchasing	PO Box 347 Rockville Centre, NY 11571-0347	516 764-4445
D	Georgia-Pacific Corp.	Jim Herbig, Buyer Lumber	PO Box 105605 Atlanta, GA 30348-5605	404 652-4000
D	Grove Lumber & Building Supplies Inc.	Paul Haacke, Buyer Lumber	1344 S Bon View Ave Ontario, CA 91761-4403	909 947-1312
D	GROWMARK Inc.	Don Wilkey, Director Purchasing Lumber	PO Box 2500 Bloomington, IL 61702-2500	309 557-6000
D	Gunton Corp.	Joe Bobnar, General Buyer	26150 Richmond Rd Bedford Heights, OH 44146-1438	216 831-1206

D/R	Company	Contact	Address	Phone
D	Hager Group Company	Tom Kline, Buyer Lumber	PO Box 912 Grand Rapids, MI 49509-0912	616 452-5151
D	Hampton Lumber Sales Co.	Carter Stinton, General Buyer	9400 SW Barnes Rd Ste 400 Portland, OR 97225-6660	503 297-7691
D	Handy Hardware Wholesale Inc.	John Newell, Buyer Lumber	PO Box 12847 Houston, TX 77217-2847	713 644-1495
D	Hankins Lumber	Richard Rothwell, Buyer Lumber	PO Box 1397 Grenada, MS 38902-1397	601 226-2961
D	Harding Glass Industries	Steve Wisdom, General Buyer	7201 W 110th St Ste 200 Overland Park, KS 66210-2343	913 469-6300
D	Hardware Distribution Warehouses Inc.	Willie House, Merchandise Manager Windows & Doors	PO Box 3945 Shreveport, LA 71133-3945	318 686-8527
D	Holt & Bugbee Co.	Phillip Pierce, Buyer Lumber	PO Box 37 Tewksbury, MA 018767-0037	978 851-7201
D	Honsador Lumber Corp.	Bill Parkes, Buyer Lumber	91-151 Malakole St Kapolei, HI 96707-1893	808 682-2011
D	House-Hasson Hardware Co. Inc.	Bill Parrot, Buyer Lumber	PO Box 1191 Knoxville, TN 37901-1191	423 525-0471
D	Howard Berger Co.	Howard Berger, General Buyer	808 Georgia Ave Brooklyn, NY 11207-7704	718 272-1540
D	Hughes Supply Inc.	Eddie Gibbs, Director Purchasing	PO Box 2273 Orlando, FL 32802-2273	407 841-4755
D	Hutchison Inc.	George Hutchison Jr, VP	PO Box 358 Manchester, IA 52057-0358	319 927-3620
D	Huttig Building Products Co.	Jim Watt, Buyer Windows & Doors	PO Box 1041 Chesterfield, MO 63006-1041	314 216-2600
D	Idaho Pacific Lumber Co.	Frank Parrott, General Buyer	PO Box 190390 Boise, ID 83719-0390	208 375-8052
D	Idaho Timber Corp.	Dennis Badesheim, Buyer Lumber	PO Box 67 Boise, ID 83707-0067	208 377-3000
D	Independent Builders Supply Association Inc.	Ray Price, Buyer Windows & Doors	PO Box 2310 Smithfield, NC 27577-2310	919 934-7616
D	Intermountain-Orient Inc.	Harris Gant, Buyer Lumber	PO Box 8288 Boise, ID 83707-2288	208 384-5600

D/R	Company	Contact	Address	Phone
D	ITOCHU Building Products Co. Inc.	Mona Zinman, General Buyer	660 White Plains Rd Tarrytown, NY 10591-5107	914 366-6700
D	Ivy Hill Supplies	Scott Doyle, General Buyer	1 Ivy Hill Rd Brooklyn, NY 11211-1711	718 388-6966
D	J.E. Higgins Lumber Co.	Charles Robbins, VP Purchasing	PO Box 4124 Concord, CA 94524-4124	925 674-9300
D	J.M. Thomas Forest Products Co.	Bill Anderson, VP	PO Box 12668 Ogden, UT 84412-2668	801 782-8090
D	Jim White Lumber Sales Inc.	Dave Basner, VP Purchasing	PO Box 5949 Saginaw, MI 48603-0949	517 790-6500
D	Kelleher Corp.	Don Kelleher, CEO	PO Box 3433 San Rafael, CA 94912-3433	415 454-8861
D	Kentucky-Indiana Lumber Co.	Jim Kehl, Buyer Lumber	PO Box 2289 Louisville, KY 40201-2289	502 637-1401
D	Kevco Inc.	Mark Walker, Director Purchasing	PO Box 947015 Fort Worth, TX 76147-9015	817 332-2758
D	Klumb Lumber Co.	Steve McCary, Buyer Lumber	PO Box 5049 Jackson, MS 39296-5049	601 932-6070
D	Kobrin Builders Supply Inc.	Michael Davis, VP Operations	1401 Atlanta Ave Orlando, FL 32806-3916	407 843-1000
D	L & W Supply Corp.	George Macko, Director Purchasing	125 S Franklin St Chicago, IL 60606-4605	312 606-4000
D	Lake States Lumber Inc.	Jerry Lipovetz, Buyer Lumber	PO Box 310 Aitkin, MN 56431-0310	218 927-2125
D	Lane-Stanton-Vance Lumber Co.	Charlie Wilson, General Buyer	PO Box 92650 City of Industry, CA 91715-2650	626 968-8331
D	LaSalle Bristol Corp.	William Kinch, VP Purchasing	PO Box 98 Elkhart, IN 46615-0098	219 295-4400
D	Lavelle Co.	Robert E. Lavelle, VP	PO Box 2583 Fargo, ND 58108-2583	701 293-6501
D	Lawrence R. McCoy & Co. Inc.	Robert M. Paulson, VP Purchasing	100 Front St Worcester, MA 01680-1402	508 798-7575
D	Lensing Wholesale Inc.	Bill Theby, Buyer Windows & Doors	PO Box 965 Evansville, IN 47706-0965	812 423-6891

D/R	Company	Contact	Address	Phone
D	Louisiana-Pacific Corp.	Jeff Wagner, General Buyer	111 SW 5th Ave Portland, OR 97204-3604	503 221-0800
D	Lumber Inc.	Frank Chiado, General Buyer	PO Box 26777 Albuquerque, NM 87125-6777	505 823-2700
D	Lumber Products	Randy Wisner, Buyer Lumber	19855 SW 124th Ave Tualatin, OR 97062-8007	503 692-3322
D	Lumbermen Associates Inc.	Timothy M. Deegan, VP	PO Box 720 Bristol, PA 19007-0720	215 785-4600
D	Lumbermen's Inc.	Douglas Rathbun, Exec VP Purchasing	4433 Stafford Ave SW Grand Rapids, MI 49548-4124	616 538-5180
D	Lumbermen's Merchandising Corp.	Jim Bernardin, General Buyer	PO Box 6790 Wayne, PA 19087-8790	610 293-7000
D	Marks Forest Products Inc.	Doyal Marks, Director Purchasing	PO Box 381328 Birmingham, AL 35238-1328	205 991-5008
D	Matheus Lumber Co.	Gary Powell, Buyer Lumber	PO Box 2260 Woodinville, WA 98072-2260	425 489-3000
D	Matson Lumber Co. Inc.	Joe Spangler, Buyer Lumber	132 Main St Brookville, PA 15825-1213	814 849-5336
D	McClure-Johnston Company	William Soles, General Buyer	201 Corey Ave Braddock, PA 15104-1397	412 351-4300
D	McEwen Lumber Co.	Gordon Wiseman, Buyer Lumber	PO Box 950 High Point, NC 27261-0950	336 472-1900
D	McQuesten Co. Inc.	Douglas Keller, Buyer Lumber	600 Iron Horse Park North Billerica, MA 01862-1618	978 663-3435
D	Mellco Inc.	Randy Loggins, VP Purchasing Lumber	PO Box C Perry, GA 31069-0039	912 987-5040
D	Meyer USA Inc.	Harry Fedden, General Buyer	11465 Johns Creek Pkwy Ste 380 Duluth, GA 30097-1572	678 475-9506
D	Mid-Am Building Supply Inc.	Alan Knaebel, General Buyer	PO Box 645 Moberly, MO 65270-0645	660 263-2140
D	Mid-State Lumber Corp.	Kenneth Bernstein, VP Purchasing	200 Industrial Pkwy Somerville, NJ 08876-3488	908 725-4900
D	Mid-States Distributing Co. Inc.	Laura Summers, Buyer Lumber	PO Box 64537 Saint Paul, MN 55164-0537	651 698-8831

D/R	Company	Contact	Address	Phone
D	Milliken Millwork Inc.	Kevin Milliken, Exec VP Purchasing	PO Box 667 Sterling Heights, MI 48311-0667	810 264-0950
D	Minot Builders Supply Assoc.	Jim Nitsch, General Buyer	PO Box 1288 Minot, ND 58702-1288	701 852-1301
D	Modern Builders Supply Inc.	Jim Mills, Director Purchasing	45 Karago Rd Youngstown, OH 44512-5950	800 783-2179
D	Moore-Handley Inc.	Ed Plemons, Buyer Windows & Doors	PO Box 2607 Birmingham, AL 35202-2607	205 663-8011
D	Morgan Forest Product Inc.	Dan Bare, Buyer Lumber	PO Box 20369 Columbus, OH 43220-0369	614 457-3390
D	Morgan Products Limited	John Hornung, Director Purchasing	469 McLaws Cir Williamsburg, VA 23185-5645	757 564-1700
D	National Nail Corp.	Jack DeYoung, Buyer Windows & Doors	PO Box 2434 Grand Rapids, MI 49501-2434	616 538-8000
D	Negwer Materials Inc.	Scott Negwer, Director Operations	49 Airport Rd Saint Louis, MO 63135-1998	314 522-0579
D	Neiman Reed Lumber Co.	Ed Langley, Buyer Lumber	13301 Burbank Blvd Van Nuys, CA 91401-5322	818 781-3466
D	New South Inc.	John Thompson, VP Purchasing	PO Box 9089 Myrtle Beach, SC 29578-9089	843 236-9399
D	Norandex Inc./Reynolds Distribution Co.	Rick Martucci, Director Purchasing	8450 S Bedford Rd Macedonia, OH 44056-2033	330 468-2200
D	North Pacific Group Inc.	Don Lester, Buyer Lumber	PO Box 3915 Portland, OR 97208-3915	503 231-1166
D	Northland Corp.	Ken Wiggins, Director Purchasing	PO Box 265 La Grange, KY 40031-0265	502 222-1441
D	OrePac Building Products	Jack Alley, Buyer Lumber	30170 SW Ore Pac Ave Wilsonville, OR 97070-9794	503 685-5499
D	Orgill Inc.	Karen Meredith, Merchandise Manager Windows & Doors	PO Box 140 Memphis, TN 38101-0140	901 948-3381
D	Pacific Coast Building Products Inc.	Ray Russell, VP Purchasing	PO Box 160488 Sacremento, CA 95816-0488	916 444-9304
D	Pacific Steel & Supply	Ronald O'Connor, Director Purchasing	PO Box 1548 San Leandro, CA 94577-0380	510 357-0340

D/R	Company	Contact	Address	Phone
D	Passaic Metal & Building Supplies Co.	Craig Anderson, Buyer Lumber	PO Box 1849 Clifton, NJ 07015-1849	973 546-9000
D	Patrick Lumber Co.	Jim Rodway, VP Purchasing	828 SW 1st Ave Portland, OR 97204-3327	503 222-9671
D	Paxton The Wood Source	Ron Hutchins, VP Operations	PO Box 6610 Kansas City, MO 64123-0610	816 483-3007
D	Philadelphia Reserve Supply Co.	Ron Piazza, Buyer Lumber	400 Mack Dr Croydon, PA 19021-6996	215 785-3141
D	Pleasants Hardware Co.	Charles Hummel, Buyer Windows & Doors	PO Box 5258 Winston Salem, NC 27113-5258	336 725-3067
D	Plum Creek Lumber Co. Inc.	Don Luce, General Buyer	PO Box 1990 Columbia Falls, MT 59912-1990	406 892-6200
D	Plunkett-Webster Inc.	Joe Croft, VP	2 Clinton Pl New Rochelle, NY 10801-7416	914 636-8770
D	PrimeSource Building Products Inc.	Darren Blankenship, Buyer Windows & Doors	1800 John Connally Dr Carrollton, TX 75006-5403	972 417-3701
D	Progressive Affiliated Lumbermen Coop Inc.	Ken Jordan, Buyer Lumber	PO Box 823 Grand Rapids, MI 49518-0823	616 281-2826
D	Prudential Building Materials	Dave McKenna, Buyer Lumber	PO Box 8728 Miami, FL 33255	305 666-3321
D	Quality Roofing Supply Co. Inc.	Brian O'Neil, Buyer Lumber	2890 Hempland Rd Lancaster, PA 17601-6914	717 293-8800
D	Quality Veneer & Lumber Inc.	Tom Mayr, VP Purchasing	1325 4th Ave Ste 1428 Seattle, WA 98101-2509	206 829-2000
D	R.E. Sweeney Co. Inc.	Greg Sebastian, General Buyer	PO Box 1921 Fort Worth, TX 76101-1921	817 834-7191
D	Redwood Empire	Mike Franceschi, Buyer Lumber	PO Box 1300 Morgan Hill, CA 95038-1300	408 779-7354
D	Reliable Wholesalers Inc.	Joel Miculinic, General Buyer	28100 N Ashley Cir Ste 109 Libertyville, IL 60048-9479	847 918-1177
D	Reliable Wholesale Lumber Inc.	Daniel Higman, General Buyer	PO Box 191 Huntington Beach, CA 92645-0191	714 848-8222
D	Richmond International Forest Products	Jack Coward, VP Purchasing	PO Box 2757 Glen Allen, VA 23058-2757	804 747-0111

D/R	Company	Contact	Address	Phone
D	Robbins Manufacturing Co.	Rene Huesca, Buyer Lumber	PO Box 17939 Tampa, FL 33682-7939	813 971-3030
D	Robert Weed Plywood Corp.	Robert Weed, General Buyer	PO Box 487 Briston, IN 46507-0487	219 848-4408
D	Roberts & Dybdahl Inc.	Cyndee M. Johnson, Director Purchasing	PO Box 1908 Des Moines, IA 50306-1908	515 283-7100
D	Robinson Lumber Co. Inc.	Reginald C. Robinson, General Buyer	4000 Tchoupitoulas St New Orleans, LA 70115-1433	504 895-6377
D	Rugby Building Products Inc.	Matt Hood, Director Purchasing	2575 Westside Pkwy Ste 800 Alpharetta, GA 30004-3852	770 625-1700
D	Russin Lumber Corp.	David Jaffee, General Buyer	21 Leonards Dr Montgomery, NY 12549-2643	914 457-4000
D	Scholl Forest Industries	Ward Scholl, General Buyer	PO Box 41558 Houston, TX 77241-1558	713 329-5300
D	Schultz Snyder & Steele Lumber Co.	Donald Engler, Buyer Lumber	PO Box 24128 Lansing, MI 48909-4128	517 349-8220
D	Seaboard International Forest Products	Mike Sopher, Buyer Lumber	PO Box 6059 Nashua, NH 03063-6059	603 881-3700
D	Seven D Wholesale	Tom Poe, Buyer Lumber	3229 Pleasant Valley Blvd Altoona, PA 16602-4435	814 941-7777
D	Sherwood Lumber Corp.	Jimmy Butler, General Buyer	300 Corporate Plz Central Islip, NY 11722-1549	516 232-9191
D	Snavely Forest Products Inc.	Jim Coll, General Buyer	PO Box 9808 Pittsburgh, PA 15227-0008	412 885-4000
D	Spartanburg Forest Products Inc.	Anthony Bailey, Director Purchasing	5000 College Dr Spartansburg, SC 29303-6614	864 595-3095
D	Stringfellow Lumber Co. LLC	Bill Fisher, Buyer Lumber	PO Box 1117 Birmingham, AL 35201-1117	205 271-2400
D	Tampa International Forest Products Inc.	Dale Rodekuhr, Buyer Lumber	PO Box 23883 Tampa, FL 33623-3883	813 221-3006
D	Tech Products	Rich Cline, Buyer Lumber	3551 NW 116th St Miami, FL 33167-2923	305 685-5993
D	Ted Lansing Corp.	Scott Jordan, Exec VP	8501 Sanford Dr Richmond, VA 23228-2812	804 266-8893

D/R	Company	Contact	Address	Phone
D	Tennessee Building Products Inc.	John Whipple, VP	PO Box 100926 Nashville, TN 37224-0926	615 259-4677
D	Texas Plywood & Lumber Co. Inc.	Shirley Kirgan, General Buyer	PO Box 531110 Grand Prairie, TX 75053-1110	972 262-1331
D	The Emery-Waterhouse Co.	Pete Plowman, Director Purchasing	PO Box 659 Portland, ME 04104-5020	207 775-2371
D	The Empire Company Inc.	Doug LaDue, Director Purchasing	PO Box 17 Zeeland, MI 49464-0017	616 772-7055
D	The Goldenberg Group	Steve Byers, General Buyer	PO Box 190 Lynwood, CA 90262-0190	310 537-9870
D	The Kruse Co.	Gary Roetting, Buyer	4275 Thunderbird Ln Fairfield, OH 45014-5483	513 860-3600
D	The Palmer-Donavin Manufacturing Co.	Dave Zimmerman, Buyer Lumber	1200 Steelwood Rd Columbus, OH 43212-1371	614 486-9657
D	The Radford Co.	Jim Koch, Buyer Lumber	PO Box 2688 Oshkosh, WI 54903-2688	920 426-6200
D	TruServ Corp.	Bruce Schneider, VP Lumber	8600 W Bryn Mawr Ave Chicago, IL 60631-3502	773 695-5000
D	Tumac Lumber Co. Inc.	Jerry Gustafon, Buyer Lumber	529 SW 3rd Ave Ste 600 Portland, OR 97204-2540	503 226-6661
D	U.S. Lumber Group Inc.	Tim Parker, Buyer Lumber	PO Box 936 Greenville, SC 29602-0936	864 271-0663
D	United Hardware Distributing Co.	Bob Hinderks, Buyer Lumber	PO Box 410 Minneapolis, MN 55440-0410	612 559-1800
D	Universal Forest Products Inc.	Mike Mordell, VP Purchasing	2801 E Beltline Ave NE Grand Rapids, MI 49525-9736	616 364-6161
D	Universal Supply Co. Inc.	Jack Caruso, Buyer Lumber	PO Box 266 Hammonton, NJ 08037-0266	609 561-1213
D	Uresco Construction Material	Bill Scheffler, General Buyer	PO Box 1778 Kent, WA 98035-1778	253 395-1211
D	Vaughan & Sons Inc.	Melvin Allen, Buyer Lumber	PO Box 17258 San Antonio, TX 78217-0258	210 352-1300
D	Viking Forest Products Inc.	Jeff Ohm, Buyer Lumber	PO Box 39811 Minneapolis, MN 55439-0811	612 941-6512

D/R	Company	Contact	Address	Phone
D	Wallace Hardware Co. Inc.	Gary Hardin, Buyer Lumber	PO Box 687 Morristown, TN 37815-0687	423 586-5650
D	Wausau Supply Company	Dusty Dvorak, Buyer Windows & Doors	PO Box 296 Wausau, WI 54402-0296	715 359-2524
D	Weekes Forest Products Inc.	Bob Hanson, Buyer Lumber	PO Box 14327 Saint Paul, MN 55114-0327	651 644-9807
D	West Roofing & Supply Co. Inc.	Jerry Leech, General Buyer	602 W McCarty St Indianapolis, IN 46225-1241	317 264-1070
D	Western International Forest Products	Jeff Richmond, General Buyer	PO Box 3070 Portland, OR 97208-3070	503 246-5500
D	Western Lumber Co.	Robert Brown, Buyer Lumber	PO Box 98 Medford, OR 97501-0007	541 779-5121
D	Western Woods Inc.	Tom Vonmoos, Buyer Lumber	PO Box 4402 Chico, CA 95927-4402	530 343-5821
D	Weyerhaeuser Co.	Leanne Pollock, Director Purchasing	PO Box 9777 Federal Way, WA 98063-9777	253 924-2345
D	Wheeler Consolidated	Roy Shaffer, VP Purchasing	1100 Hoak Dr West Des Moines, IA 50265-2672	515 223-1584
D	William M. Young Co.	John Baran, Buyer Lumber	PO Box 10487 Wilmington, DE 19850-0487	302 654-4448
D	Wimsatt Building Material Corp.	Jerry Swiney, Buyer Lumber	PO Box 609 Wayne, MI 48184-0609	734 722-3460
D	Wolf Distributing Co.	Mel Lebo, Buyer Lumber	PO Box 1267 York, PA 17405-1267	717 852-4800
D	Woodford Plywood Inc.	Herbert G. Wood, General Buyer	PO Box 50007 Albany, GA 31703-0007	912 883-4900
D	Worldwide Wholesalers Inc.	Mark Remington, Buyer Building Hardware	PO Box 88607 Seattle, WA 98138-2607	253 872-8746
R	84 Lumber Co.	Jack Whitley, Director Purchasing	1019 Route 519 Eighty Four, PA 15330-2813	724 228-8820
R	Adams Building Material Inc.	Nan O'Sullivan, Manager Information Systems	1801 7th St SW Winter Haven, FL 33880-4376	863 294-0611
R	Alexander Lumber Co.	Bill Gilbert, Buyer Gypsum	PO Box 831 Aurora, IL 60507-0831	630 844-5123

D/R	Company	Contact	Address	Phone
R	Alpine Lumber Co.	Robert E. Curran, Manager Purchasing	PO Box 33676 Denver, CO 80233-0676	303 451-8001
R	Arlington Coal & Lumber Co. Inc.	John McNamara, Director Operations	41 Park Ave Arlington, MA 02476-4180	781 643-8100
R	Arnold Lumber Co. Inc.	Dave Beattie, Buyer Paneling & Plywood	PO Box 217 West Kingston, RI 02892-0217	401 783-2266
R	Associated Truss & Lumber Co.	Jerry MaGee, General Buyer	PO Box 851629 Mesquite, TX 75185-1629	972 226-0768
R	Bailey Lumber & Supply Co.	Jimmy Cooper, General Buyer	PO Box 6056 Gulfport, MS 39506-6056	228 896-6071
R	Barr Lumber Co. Inc.	Buck Byers, VP	111 E Mill St San Bernardino, CA 92408-1406	909 884-4744
R	Belletetes Inc.	Geoff Harris, Buyer Millwork (Molding)	51 Peterborough St Jaffrey, NH 03452-5865	603 532-7716
R	Bellevue Builders Supply Inc.	Monica Bourst, Buyer Ceilings & Skylights	700 Duanesburg Rd Schenectady, NY 12306-1019	518 355-7190
R	Bender Lumber Co. Inc.	Tony Walker, Director Merchandising	2051 W Vernal Pike Bldg 1 Bloominton, IN 47404-2872	812 339-9730
R	Berks Products Corp.	Glenn Unger, General Buyer	PO Box 421 Reading, PA 19603-0421	610 374-5131
R	Big C Lumber Co. Inc.	Bill Kuminecz, Buyer Trusses	50860 Princess Way Granger, IN 46530-8478	574 277-4550
R	Big Creek Lumber Co. Inc.	Ken Walls, Manager Branch	3564 Highway 1 Davenport, CA 95017-9706	831 423-4156
R	Bison Building Materials Ltd.	Rick Hutzler, Manager Purchasing	PO Box 19849 Houston, TX 77224-9849	713 467-6700
R	Bloedorn Lumber Co.	Tom Worley, VP	PO Box 1077 Torrington, WY 82240-1077	307 532-2151
R	BMHC	Dan Mandeville, Manager Purchasing	PO Box 70006 Boise, ID 83707-0106	208 331-4300
R	Buchheit Inc.	Doug Buchheit, General Buyer	33 Pcr 540 Perryville, MO 63775-8757	573 547-1010
R	Builder Resource	Chad Everhart, Buyer Windows & Doors	9701 W 67th St Ste Shawnee, KS 66203-3673	913 362-9555

D/R	Company	Contact	Address	Phone
R	Builders FirstSource Inc.	John Gunn, VP Purchasing Trusses	2001 Bryan St Ste 1600 Dallas, TX 75201-3017	214 880-3500
R	Builders General Supply Co.	John Ferrie, Manager Purchasing	15 Sycamore Ave Little Silver, NJ 07739-1200	732 747-0808
R	Builders Supply Co. Inc.	Les Green, Buyer Windows & Doors	PO Box 27109 Omaha, NE 68127-0109	402 331-4500
R	Burton Lumber & Hardware Co.	Ben Sanders, Buyer Millwork (Molding)	2220 S State St Salt Lake City, UT 84115-2785	801 487-8861
R	Busy Beaver Building Centers Inc.	Amy Puto, Buyer Masonry	3130 William Pitt Way Pittsburgh, PA 15238-1360	412 828-2323
R	Cape Cod Lumber Co. Inc.	Mel Westerman, VP Purchasing	403 Bedford St Abington, MA 02351-1995	781 878-0715
R	Capitol Building Supply Inc.	Ken Carter, General Buyer	8429 Euclid Ave Manassas, VA 20111-2375	703 631-6633
R	Carolina Holdings Inc.	Robin Green, VP Purchasing	PO Box 58515 Raleigh, NC 27658-8515	919 431-1000
R	Carter Lee Lumber Co. Inc.	Curt Englert, Manager Purchasing	1717 W Washington St Indianapolis, IN 46222-4542	317 639-5431
R	Carter-Jones Lumber Co.	Bill Wollsey, Buyer Lumber	601 Tallmadge Rd Kent, OH 44240-7331	330 673-6100
R	Cassity Jones Lumber & Hardware Inc.	Cecil Pinson, COO	302 Pine Tree Rd Longview, TX 75604-4106	903 759-0736
R	Causeway Lumber Co. Inc.	Mike Coleman, Director Purchasing Building Hardware	PO Box 21088 Fort Lauderdale, FL 33335-1088	954 763-1224
R	Central Valley Builders Supply	Kathy Stoner, General Buyer	1100 Vintage Ave Saint Helena, CA 94574-1440	707 963-3622
R	Champion Lumber Co.	Clark Taylor, Buyer Lumber	PO Box 55068 Riverside, CA 92517-0068	909 684-5670
R	Chase-Pitkin Home & Garden	Jerry Metzger, Buyer Trusses	3131 Winton Rd S Rochester, NY 14623-2905	585 427-8100
R	Choo Choo Build-It Mart	Joe Inman, General Buyer	PO Box 1659 Vidalia, GA 30475-1659	912 537-8964
R	City Mill Co. Ltd.	Eric Yamashita, Buyer Paints	PO Box 1559 Honolulu, HI 96806-1559	808 533-3811

D/R	Company	Contact	Address	Phone
R	Clay Ingels Co. LLC	Henry Barnes, Buyer Windows & Doors	PO Box 2120 Lexington, KY 40588-2120	859 252-0836
R	Concord Lumber Corp.	Paul Torca, VP	PO Box 1526 Littleton, MA 0146-4526	978 486-9877
R	Consolidated Lumber Co.	Jim Moenck, General Buyer	808 4th St N Stillwater, MN 55082-4004	651 439-3138
R	Contract Lumber Inc.	Andy Bosworth, Manager Purchasing	3245 Hazelton Etna Rd SW Pataskala, OH 43062-8532	740 927-4242
R	Contractors Warehouse	Jack Holland, General Buyer	3222 Winona Way Ste 201 North Highlands, CA 95660-5523	916 331-5934
R	Cox Lumber Co.	Richard Pickens, Director Purchasing	3300 Fairfield Ave S Saint Petersburg, FL 33712-1899	727 327-4503
R	Crosslin Supply Co. Inc.	Greg Davis, Buyer Lumber	PO Box 309 Smyrna, TN 37167-0309	615 459-2854
R	Curtis Lumber Co. Inc.	John Kirk, Manager Purchasing	885 State Route 67 Ballston Spa, NY 12020-3689	518 885-5311
R	Davidson Industries Inc.	Dave de Hebreard, Manager Purchasing Trusses	PO Box 800 Franklin, IN 46131-0800	317 738-3211
R	Discount Builders Supply	Murray Gelleri, General Manager	6095 Mission Blvd San Francisco, CA 94124	415 285-2800
R	Dixieline Lumber Co.	Bill Shadden, Director Merchandising	PO Box 85307 San Diego, CA 92186-5307	619 224-4120
R	Doug Ashy Building Materials Inc.	Doug Ashy Jr, President	4950 Johnston St Lafayette, LA 70503-4801	337 984-2110
R	Dykes Lumber Co. Inc.	Mike White, Buyer Insulation	PO Box 857 Weehawken, NJ 07087-0857	201 867-0391
R	E.C. Barton & Co.	Frank DiGaetano, Manager Purchasing	PO Box 4040 Jonesboro, AR 72403-4040	870 932-6673
R	Edward Hines Lumber Co.	John Vetter, Senior VP Purchasing	1000 Corporate Grove Dr Buffalo Grove, IL 60089-4550	847 353-7700
R	Ellsworth Builders Supply Inc.	Robert S. Jancewicz, VP Purchasing	261 State St Ellsworth, ME 04605-3332	207 667-7134
R	F.E. Wheaton & Co. Inc.	Neil Kristianson, General Buyer	204 W Wheaton Ave Yorkville, IL 60560-4545	630 553-8300

D/R	Company	Contact	Address	Phone
R	Fagen's Building Centers Inc.	Jim Cardiali, Director Purchasing	PO Box 658 Wexford, PA 15090-0658	724 935-3700
R	Farmers Cooperative Elevator Co.	Joe Grothe, General Buyer	PO Box 24 Arcadia, IA 51430-0024	712 689-2296
R	Fingerle Lumber Co.	Mark M. Fingerle, Partner	PO Box 1167 Ann Arbor, MI 48106-1167	734 663-0581
R	Florence Corporation	Tony Blados, Buyer Lumber	1647 E Jericho Tpke Huntington, NY 11743-5711	631 499-6200
R	Forest Products Supply Inc.	Joe Cho, Manager Division Lumber	PO Box 21359 Sarasota, FL 34276-4359	941 922-0731
R	Foxworth-Galbraith Lumber Co.	Bert Solt, Buyer Trusses	PO Box 799002 Dallas, TX 75379-9002	972 437-6100
R	Franklin Building Supply Co.	Stan Buscher, Buyer Siding/soffit/fascia	11700 Franklin Rd Boise, ID 83709-0139	208 322-4567
R	Friedman Brothers Hardware	Brian Pierce, Buyer Trusses	4055 Santa Rosa Ave Santa Rosa, CA 95407-8222	707 584-7811
R	Ganahl Lumber Co.	Michael Seeds, VP Purchasing	PO Box 31 Anaheim, CA 92815-0031	714 772-5444
R	Gilcrest-Jewett	Brad Schulte, Buyer Windows & Doors	PO Box 1000 Waukee, IA 50263-1000	515 987-3600
R	Golden State Lumber	Bob Nave, Buyer Gypsum	719 Southpoint Blvd Petaluma, CA 94954-1495	707 769-0181
R	Gordon Lumber Co.	Mike Hock, General Buyer	PO Box 241 Oak Harbor, OH 43449-0241	419 333-5444
R	Graber Post Buildings Inc.	Steve Graber, VP Purchasing	RR 1 Box 225 Montgomery, IN 47558-9625	812 636-7355
R	Gracious Home	Jordan Milowitz, VP Purchasing	632 Broadway New York, NY 10012-2614	212 901-6303
R	Great Central Lumber Co. Inc.	Tony Millman, General Buyer	9264 Manchester Rd Saint Louis, MO 63144-2697	314 968-1700
R	Grossman's	Laury Rovner, VP Merchandising	90 Hawes Way Stoughton, MA 02072-1163	781 297-3300
R	Guy C. Lee Building Materials	Patty Ennis, COO	PO Box 1457 Clayton, NC 27520-1400	919 934-6195

D/R	Company	Contact	Address	Phone
R	Gypsum Management & Supply	Russ Mazza, Director Purchasing	PO Box 1528 Tucker, GA 30085-1528	770 939-1711
R	Hacienda Home Centers Inc.	Angie Romero, Director Purchasing	PO Box 30148 Alburquerque, NM 87190-0148	505 884-8811
R	Hall & House Lumber Co. Inc.	Roger D. Hall, Partner	PO Box 47710 Indianapolis, IN 46247-0710	317 783-4177
R	Hamilton Farm Bureau Co-Op Inc.	Scott VanderKolh, Buyer Vanities	PO Box 186 Hamilton, MI 49419-0186	616 751-5171
R	Hammond Lumber Company	Matt Masse, Manager Purchasing	PO Box 500 Belgrade, ME 04917-0500	207 495-3303
R	Hancock Lumber Co. Inc.	Camille Dubois, Director Purchasing Trusses	PO Box 299 Casco, ME 04015-0299	207 627-4201
R	Hartje Lumber Inc.	Jim Klang, Buyer Windows & Doors	PO Box 389 La Valle, WI 53941-0389	608 985-7207
R	Hawaii Planing Mill Ltd.	Melvin Revilla, Buyer Siding/soffit/fascia	16-166 Melekahiwa St Keaau, HI 96749-8016	808 966-5466
R	Hayward Lumber Co. Inc.	Mike Spengler, Manager Building Hardware	PO Box 16009 Monterey, CA 93942-6009	831 643-1900
R	Herrington's Inc.	Bob Hall, Director Purchasing	PO Box 709 Hillsdale, NY 12529-0709	518 325-3131
R	Holmes Lumber & Building Center Inc.	Henry Wengerd, Buyer Lumber	6139 State Route 39 Millersburg, OH 44654-8845	330 674-9060
R	Home Lumber & Hardware Co. Inc.	John Svec, Director Purchasing	PO Box 80 Thompsons, TX 77481-0080	281 238-1100
R	Home Lumber Co.	Dale McCormick, Buyer Windows & Doors	PO Box 6305 San Bernardino, CA 92412-6305	909 381-1771
R	Hope Lumber & Supply Co.	Jim Miller, General Buyer	12215 E 61st St Broken Arrow, OK 74012-9115	918 249-0909
R	Hormuth Group Inc.	Steve Hormuth, President	2600 S Susan St Santa Ana, CA 92704-5816	714 751-0800
R	Hundman Lumber Do-It Center	Doug Dyson, Buyer Trusses	1707 E Hamilton Rd Bloominton, IL 61704-9607	309 662-0339
R	Jackson Lumber & Millwork Co. Inc.	Alfred J. Torrisi, President	PO Box 449 Lawrence, MA 01842-0949	978 686-4141

D/R	Company	Contact	Address	Phone
R	Jaeger Lumber & Supply Co.	John Dangerfield, Manager Building Hardware	PO Box 126 Union, NJ 07083-0126	908 686-0073
R	Jones Lumber Co. Inc.	Victor Estrella, General Buyer	PO Box 40 Lynwood, CA 90262-0040	323 564-6656
R	JT's Lumber LLC	Larry Feeney, General Buyer	PO Box 4509 Middletown, RI 02842-0509	401 846-2000
R	Kaplan Lumber Co. Inc.	Bob Moseler, President	PO Box 340 Saint Peters, MO 63376-0006	636 946-6971
R	Keith Brown Building Materials Inc.	Dave Paldino, VP Purchasing	PO Box 806 Salem, OR 97308-0806	503 584-2000
R	Kempsville Building Materials	Alexander Lucci, General Buyer	PO Box 62467 Virginia Beach, VA 23466-2467	757 497-9392
R	Kentucky-Indiana Lumber Co.	Walt Freeman, President	PO Box 2289 Louisville, KY 40201-2289	502 637-1401
R	Kleet Lumber Co.	Eugene Wolff, Buyer Building Hardware	777 Park Ave Huntington, NY 11743-3993	631 427-7060
R	Knecht Ace Hardware Inc.	Darrell Haffner, General Buyer	320 West Blvd Rapid City, SD 57701-2671	605 342-4840
R	Kuiken Brothers Co. Inc.	Doug Kuiken, General Buyer	PO Box 1040 Fair Lawn, NJ 07410-8040	201 796-2082
R	Lampert Yards	Brian Stoen, VP Purchasing	1850 Como Ave Saint Paul, MN 55108-2715	651 695-3600
R	Lampert Yards	John Wigen, Buyer Millwork (Molding)	1850 Como Ave Saint Paul, MN 55108-2715	651 695-3600
R	Lanoga Corp.	Rick Thornton, VP Purchasing	PO Box 97040 Redmond, WA 98073-9740	425 883-4125
R	LaValley Building Supply Inc.	Kevin Snide, Buyer Ceilings & Skylights	PO Box 267 Newport, NH 03773-0267	603 863-1050
R	Leeds Building Products Inc.	Art Cassidy, VP Purchasing	2105 Barrett Park Dr NW Ste 10 Kennesaw, GA 30144-7080	770 421-2950
R	Lezzer Cash & Carry Inc.	Dennis Lezzer, Buyer Ceilings & Skylights	PO Box 217 Curwensville, PA 16833-0217	814 236-0220
R	Livonia Building Materials Co.	Ronald Lazo, Buyer Millwork (Molding)	33000 Concord Livonia, MI 48150	734 421-1170

D/R	Company	Contact	Address	Phone
R	Louis J. Grasmick Lumber Co.	Doug Myers, VP Purchasing	6715 Quad Ave Baltimor, MD 21237-2499	410 325-9663
R	Lowe's Companies Inc.	K. Scott Plemmons, VP Merchandising	PO Box 1111 North Wilesboro, NC 28659-1111	336 658-4000
R	Lumber City Corp.	Mike Mauck, GMM	20525 Nordhoff St Ste 210 Chatsworth, CA 91311-6100	818 407-3888
R	Lumber Investors Inc.	Jim McGinity, General Buyer	PO Box 5919 Alexandria, LA 71307-5919	318 448-0590
R	Lumber One	Scott Eichers, General Buyer	PO Box 7 Avon, MN 56310-0007	320 356-7342
R	Lummus Supply Co. Inc.	Heidi Lummus, Buyer Lumber	1554 Bolton Rd NW Atlanta, GA 30331-1099	404 794-1501
R	Lyman Lumber Co.	Jim Stensvold, Manager Division Millwork (Molding)	PO Box 40 Excelsior, MN 55331-0040	952 470-3600
R	Lyon & Billard Co.	Alan Goralnik, Exec VP	PO Box 874 Meriden, CT 06450-0874	203 235-4487
R	M.G. Building Materials Inc.	Thomas Grothues, Exec VP	9501 Hwy 81 S San Antonio, TX 78211	210 924-5131
R	Magbee Contractors Supply	Greg Hawley, Manager Purchasing Ceilings & Skylights	2883 Pleasant Hill Rd Duluth, GA 30096-3806	770 476-4000
R	Maner Builders Supply Co.	Steve Antopolsky, General Buyer	PO Box 204598 Augusta, GA 30917-4598	706 863-6191
R	Manning Building Supplies Inc.	Greg Bangart, Manager Information Systems	10900 Phillips Hwy Jacksonville, FL 32256-1551	904 268-7000
R	Marjam Supply Inc.	Theresa Scanlon, Director Purchasing	885 Conklin St Farmingdale, NY 11735-2400	631 249-4900
R	Marling Lumber Co.	Greg Hirsch, Buyer Lumber	PO Box 7668 Madison, WI 53707-7668	608 244-4777
R	Marvin's Inc.	Darrin Gilliam, VP Marketing	PO Box 1110 Leeds, AL 35094-5110	205 702-7305
R	McCoy's Building Supply Centers	David Dollar, Manager Purchasing	PO Box 1028 San Marcos, TX 78667-1028	512 353-5400
R	McCray Lumber Co.	Dennis Donnelly, VP	PO Box 7230 Shawnee Mission, KS 66207-0230	913 341-6900

D/R	Company	Contact	Address	Phone
R	McLendon Hardware Inc.	Craige Holmes, Buyer Trusses	715 Lind Ave SW Renton, WA 98055-2306	425 235-3592
R	Mead Clark Lumber Co. Inc.	Jeff Scott, Exec VP	PO Box 529 Santa Rosa, CA 95402-0529	707 576-3333
R	Mead Lumber Co. Inc.	Calvin Riley, Manager Advertising	PO Box 878 Columbus, NE 68602-0878	402 564-5225
R	Meek's The Builders Choice	Dave Carmichael, Director Purchasing	PO Box 1746 Springfield, MO 65801-1746	417 521-2801
R	Menard Inc.	Steve Piontek, Buyer Paneling & Plywood	4777 Menard Dr Eau Claire, WI 54703-9604	715 876-5911
R	Metropolitan Lumber & Hardware & Building Supply	Spencer Simon, Buyer Building Hardware	617 11th Ave New York, NY 10036-2001	212 246-9090
R	Mill Creek Lumber & Supply Co.	Toran Ballone, Buyer Windows & Doors	PO Box 4770 Tulsa, OK 74159-0770	918 747-8027
R	Millard Lumber Inc.	Steve Fitzpatrick, General Buyer	PO Box 45445 Omaha, NE 68145-0445	402 896-2800
R	Moore's Lumber & Building Supplies Inc.	Bob E. Roach, Manager Purchasing	PO Box 2908 Roanoke, VA 24022-2908	540 982-5900
R	Moynihan North Reading Lumber Co.	David McFarland, General Buyer	PO Box 128 North Reading, MA 01864-0128	978 664-3310
R	N.A. Mans & Sons Inc.	Jim St. Pierre, Buyer Building Hardware	PO Box 202 Trenton, MI 48183-0202	734 676-3000
R	Nassau Suffolk Lumber & Supply Corp.	Kevin Romeyk, Buyer Trusses	2000 Ocean Ave Ronkonkoma, NY 11779-6581	631 467-2020
R	National Home Center Inc.	John Walters, GMM	PO Box 789 Sprindale, AR 72756-0789	479 756-1700
R	National Lumber Co.	Tom Polk, Manager Purchasing	PO Box 1003 Warren, MI 48090-1003	586 775-8200
R	National Lumber Co.	Marc Osborne, VP Purchasing	PO Box 32 Mansfield, MA 02048-0032	508 339-8020
R	New Bern Building Supply Co.	Dean Adams, General Buyer	PO Box 12305 New Bern, NC 28561-2305	252 638-5861
R	Nickerson Lumber Co. Inc.	Greg Meier, Manager Purchasing Lumber	PO Box 99 Orleans, MA 02653-0099	508 255-0200

D/R	Company	Contact	Address	Phone
R	O.C. Cluss Lumber Co.	James Baker, VP Purchasing Building Hardware	PO Box 696 Uniontown, PA 15401-0696	724 438-1959
R	P.E. Dolan Lumber Co.	Michael Spendvert, General Buyer	1117 Erickson Rd Concord, CA 94520-3701	925 686-1734
R	Parker's Lumber Co.	Gerald Theriot, General Buyer	PO Box 20439 Beaumont, TX 77720-0439	409 722-0469
R	Parr Lumber Co.	Matthew Jeffries, Director Purchasing Lumber	PO Box 849 Hillsboro, OR 97123-0849	503 614-2500
R	Piedmont Lumber & Mill Co.	Tom Markey, Buyer Lumber	395 Taylor Blvd Ste 225 Pleasant Hill, CA 94523-2292	925 674-8770
R	Ply-Marts Inc.	G. Thomas Mahaffey, VP Purchasing	PO Box 4050 Norcross, GA 30091-4050	770 447-5338
R	R.P. Lumber Co. Inc.	Robert L. Plummer, President	514 E Vandalia St Edwardsville, IL 62025-1855	618 656-1514
R	Raymond Building Supply Corp.	Don Treise, Manager Millwork (Molding)	7751 Bayshore Rd Fort Myers, FL 33917-3506	941 731-8300
R	Ridout Lumber Companies of Arkansas & Missouri	Kirk Smith, Buyer Paneling & Plywood	125 Henry Farrar Dr Searcy, AR 72143-7326	501 268-3929
R	Riemeier Lumber Co. Inc.	Maurice Barker, VP Purchasing	1150 Tennessee Ave Cincinnati, OH 45229-1000	513 242-3788
R	Riggs Supply Co. Inc.	Tony Cannon, Director Purchasing	1240 Riggs St Kennett, MO 63857-1338	573 888-9501
R	Ring's End Inc.	Rob Campbell, VP	PO Box 1066 Darien, CT 06820-1066	203 655-2525
R	Rio Grande Co.	Dave Wenman, Buyer Windows & Doors	PO Box 17227 Denver, CO 80217-0227	303 825-2211
R	RIVCO	Roger Kenniston, Director Purchasing	PO Box 8800 Penacook, NH 03303-880	603 753-6318
R	Riverhead Building Supply Corp.	William Martin, Buyer Windows & Doors	1295 Pulaski St Riverhead, NY 11901-4800	631 727-1400
R	Roper Bros. Lumber Co. Inc.	Eddie Cox, Director Purchasing	PO Box 488 Colonial Heights, VA 23834-0488	804 732-9321
R	Rowley Building Products Corp.	Joe Begnoche, Manager Purchasing Fasteners	40 Golf Links Rd Middletown, NY 10940-2624	845 343-7742

D/R	Company	Contact	Address	Phone
R	Samuel Feldman Lumber Co. Inc.	Kevin Bull, Buyer Trusses	300 N Henry St Brooklyn, NY 11222-1909	718 786-7777
R	San Lorenzo Lumber Inc.	Barry Martin, Buyer Ceilings & Skylights	PO Box 1808 Santa Cruz, CA 95061-1808	831 426-1020
R	Scherer Brothers Lumber Co.	Kris Scherer, Buyer Paneling & Plywood	9110 83rd Ave N Ste Brooklyn Park, MN 55445-2197	612 379-9633
R	Scherer Brothers Lumber Co.	Bill Maher, Buyer Windows & Doors	9110 83rd Ave N Ste Brooklyn Park, MN 55445-2197	612 379-9633
R	Seigle's Home & Building Center	Kurt Dallesasse, Buyer Ceilings & Skylights	1331 Davis Rd Elgin, IL 60123-1364	847 742-2000
R	Shelly Enterprises Inc.	Dave Moyer, Buyer Windows & Doors	PO Box 175 Perkasie, PA 18944-0175	215 723-5108
R	Spahn & Rose Lumber Co.	R. K. Guthrie, Exec VP	PO Box 149 Dubuque, IA 52004-0149	563 582-3606
R	Star Lumber & Supply Co.	Kathy Ewertz, Buyer Ceilings & Skylights	PO Box 7712 Wichita, KS 67277-7712	316 942-2221
R	Stine Lumber Co.	Dennis Stine, President	1509 S Huntington St Sulphur, LA 70663-5800	337 527-0121
R	Sutherland Lumber Co.	Herb Hughes, Buyer Ceilings & Skylights	4000 Main St Kansas City, MO 64111-2326	816 756-3000
R	T.H. Rogers Lumber Co. Inc.	Don Frencken, DMM	PO Box 5770 Edmond, OK 73083-5770	405 330-2181
R	T.W. Perry	Reggie Loun, General Buyer	8513 Connecticut Ave Chevy Chase, MD 20815-6826	301 652-2600
R	The A.C. Houston Lumber Co.	Mike Brown, General Buyer	PO Box 337410 North Las Vegas, NV 89033-0041	702 633-5100
R	The A.G. Mauro Co.	Jerry Richmond, VP	310 Alpha Dr Pittsburgh, PA 15238-2908	412 782-6600
R	The Andersons Inc.	Bruce Dolgoff, Buyer Paints	PO Box 119 Maumee, OH 43537-0119	419 893-5050
R	The Building Center Inc.	Steve Byrd, General Buyer	PO Box 357 Pineville, NC 28134-0357	704 552-8182
R	The Home Depot Inc.	Ron Jarvis, VP Merchandising Lumber	2455 Paces Ferry Rd NW Atlanta, GA 30339-4024	770 433-8211

D/R	Company	Contact	Address	Phone
R	The Mentor Lumber & Supply Co.	Vic Giaconia, General Buyer	PO Box 599 Mentor, OH 44061-0599	440 255-8814
R	The Standard Companies Inc.	Peter Rottschafer, VP Purchasing	1535 Kalamazoo Ave SE Grand Rapids, MI 49507-2129	616 243-1848
R	The Sterling Lumber & Investment Co.	James Dudenkauf, VP Operations	PO Box 211428 Denver, CO 80221-0393	303 427-9661
R	The Stevenson Group	Larry Linden, General Manager	1585 Monroe Turnpike Stevenson, CT 06491	203 261-2555
R	The Strober Organization Inc.	Tony Ciampaglia, VP	Pier 3 Furman St Brooklyn, NY 11201	718 875-9700
R	Theut Products Inc.	Elena Theut, VP	73408 Van Dyke Rd Romeo, MI 48065-3214	586 752-4541
R	Thompson Building Materials	Marty Hudson, Manager Inventory	282 S Anita Dr Orange, CA 92868-3311	714 935-0900
R	Tualatin Valley Builders Supply Inc.	Cheri Kaufman, Director Purchasing	PO Box 1138 Lake Oswego, OR 97035-0504	503 598-7477
R	United Builders Supply Co. Inc.	Michael Slosberg, President	PO Box 1728 Westerly, RI 02891-0912	401 596-2831
R	Valu Home Centers	Dan Diemert, Buyer Ceilings & Skylights	PO Box 1410 Buffalo, NY 14240-1410	716 825-7377
R	W.E. Aubuchon Co. Inc.	Bernard W. Aubuchon Jr, VP Purchasing	95 Aubuchon Dr Westminster, MA 01437-1470	978 874-0521
R	Warren Lumber & Millwork Inc.	Richard Gagnon, General Buyer	PO Box 231 Washington, NJ 07882-0231	908 835-4200
R	Watonwan Farm Service (WFS)	Dale Kettner, Manager Construction	233 E Ciro St Truman, MN 56088-1321	507 776-2831
R	West Elizabeth Lumber Co.	William R. Hoag, CEO	1 Chicago Ave Elizabeth, PA 15037-1766	412 384-3900
R	West End Lumber Co. Inc.	Kerry Sanders, Buyer Roofing	9335 Highway 6 N Houston, TX 77095-2499	281 463-7575
R	Westside Building Materials Corp.	Richard Peckham, VP Operations	PO Box 711 Anaheim, CA 92851-0711	714 385-1644
R	Wheeler's	Henry White, Director Purchasing	2 Riverside Industrial Park NE Rome, GA 30161-7301	706 232-2400

D/R	Company	Contact	Address	Phone
R	Wickes Lumber Inc.	John Bavester, Merchandise Manager	706 N Deerpath Dr Vernon Hills, IL 60061-1898	847 367-3400
R	William M. Young Co.	Harold West, President	PO Box 10487 Wilmington, DE 19850-0487	302 654-4448
R	Williams Brothers Lumber Company	Dwight Self, Buyer Windows & Doors	PO Box 8 Duluth, GA 30096-0008	770 623-2700
R	Wolf Organization Inc.	Gerry Roth, Buyer Lumber	PO Box 1267 York, PA 17405-1267	717 852-4800
R	Wolohan Lumber Co.	John Kayea, Director Purchasing	PO Box 3235 Saginaw, MI 48605-3235	989 793-4532
R	Woodhaven Lumber & Millwork Inc.	Alan Robinson, CEO	PO Box 870 Lakewood, NJ 08701-0870	732 901-0030
R	Yardbirds Electric & Plumbing Inc.	Carroll Hudson, Director Purchasing	1310 Clegg St Petaluma, CA 94954-1177	707 762-5600
R	Your Building Centers Inc.	Judy Machmer, Buyer Paneling & Plywood	PO Box 1230 Altoona, PA 16603-1230	814 944-9436
R	Zarsky Lumber Co. Inc.	Dan Coleman, CEO	PO Box 2527 Victoria, TX 77902-2527	361 573-2479
R	Zeeland Lumber & Supply Co. Inc.	Mike Pikaart, Buyer Windows & Doors	PO Box 20 Zeeland, MI 49464-0020	616 772-2119

Appendix 6: LnO Questionnaire

MATERIAL USAGE AND BUILDING APPLICATION SURVEY

Instructions: The objective of this survey is to identify the important factors in the selection of materials in building applications. In the following sections, you are asked to give your opinion of durability issues, substitution potential, and use of materials in building applications. Your answers to these questions will be used to develop materials with improved performance capabilities. All answers are strictly confidential.

- **Have you participated in facilities maintenance or base construction projects within the last five years?**

☐ YES
☐ NO

(If "NO," please give this to the appropriate person in your organization. If "YES," please go to question 1.)

1. Considering your experience at your installation, please specify the three most problematic building components, in terms of durability, and their associated type of durability problem.

BUILDING COMPONENT	TYPE OF DURABILITY PROBLEM*

*Studies show that the major types of durability problems for building components are the result of damage from:

- Moisture (fungal decay, expansion and warping)
- Fungal decay
- Mold
- Poor retention of finish (paint, stain)
- Insect (mainly termites)
- Weathering (UV from sunlight, surface erosion
- Mechanical stresses (other than wind or earthquake)
- Poor design
- Improper installation
- Fire
- Structural overload (wind, hurricanes, tornadoes, and earthquakes)

2. What are your perceptions of the durability of the following general applications? Rate each application with 0 = low durability to 5 = high durability. For all the applications that you rate lower than 3, please indicate the type of durability problem that is the major reason for the failure mode. You may wish to refer to the types of durability problems listed above. *(Circle one number for each application.)*

APPLICATIONS	LOW DURABILITY					HIGH DURABILITY	For applications rated lower than 3, please indicate the type of durability problem
Wall framing	**0**	**1**	**2**	**3**	**4**	**5**	______
I joists	**0**	**1**	**2**	**3**	**4**	**5**	______
Beams/headers	**0**	**1**	**2**	**3**	**4**	**5**	______
Roofing	**0**	**1**	**2**	**3**	**4**	**5**	______
Roof trusses	**0**	**1**	**2**	**3**	**4**	**5**	______
Roof sheathing	**0**	**1**	**2**	**3**	**4**	**5**	______
Floor underlayment	**0**	**1**	**2**	**3**	**4**	**5**	______
Interior doors	**0**	**1**	**2**	**3**	**4**	**5**	______
Exterior door framing	**0**	**1**	**2**	**3**	**4**	**5**	______
Window lineals	**0**	**1**	**2**	**3**	**4**	**5**	______

Siding	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Fascia, soffit, & corners	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Deck boards/stair treads	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Deck railing systems	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Sill plates	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Kitchen cabinets	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Bathroom cabinets	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Fencing	**0**	**1**	**2**	**3**	**4**	**5**	______________________

For the purposes of this questionnaire, woodfiber-plastic composites (WPC) are defined as a composite material made of wood combined with plastic.

3a. Have you ever used woodfiber-plastic composites at your facility? *(Please click on the box next to your answer.)*

☐ YES
☐ NO
☐ DON'T KNOW

(If "NO" or "Don't Know," please go to question 4. If "YES," please go to question 3b.)

3b. What building application(s) have you used woodfiber plastic composites, and what was the month and year of the first time you used these composites for each application you have listed? *(Please estimate if necessary.)*

Building Application (Woodfiber Plastic Composite Use)	**Month/Year of First Time Used**

4. What are your perceptions of the **CURRENT SUBSTITUTION POTENTIAL** of woodfiber-plastic composites when used in the following building applications? Consider physical (durability, shrink-swell etc.), and mechanical (structural strength, stiffness, etc.), requirements for each application in addition to cost issues. Rate each application with 0 = no potential to 5 = the most potential. *(Click on the box next to the number selected for each application.)*

APPLICATIONS	**NO POTENTIAL**					**MOST POTENTIAL**
Wall framing	**0** ☐	**1** ☐	**2** ☐	**3** ☐	**4** ☐	**5** ☐
I joists	**0** ☐	**1** ☐	**2** ☐	**3** ☐	**4** ☐	**5** ☐
Beams/headers	**0** ☐	**1** ☐	**2** ☐	**3** ☐	**4** ☐	**5** ☐
Roofing	**0** ☐	**1** ☐	**2** ☐	**3** ☐	**4** ☐	**5** ☐
Roof trusses	**0** ☐	**1** ☐	**2** ☐	**3** ☐	**4** ☐	**5** ☐
Roof sheathing	**0** ☐	**1** ☐	**2** ☐	**3** ☐	**4** ☐	**5** ☐
Floor underlayment	**0** ☐	**1** ☐	**2** ☐	**3** ☐	**4** ☐	**5** ☐
Interior doors	**0** ☐	**1** ☐	**2** ☐	**3** ☐	**4** ☐	**5** ☐
Exterior door framing	**0** ☐	**1** ☐	**2** ☐	**3** ☐	**4** ☐	**5** ☐
Window lineals	**0** ☐	**1** ☐	**2** ☐	**3** ☐	**4** ☐	**5** ☐
Siding	**0** ☐	**1** ☐	**2** ☐	**3** ☐	**4** ☐	**5** ☐
Fascia, soffit, & corners	**0** ☐	**1** ☐	**2** ☐	**3** ☐	**4** ☐	**5** ☐
Deck boards/stair treads	**0** ☐	**1** ☐	**2** ☐	**3** ☐	**4** ☐	**5** ☐
Deck railing systems	**0** ☐	**1** ☐	**2** ☐	**3** ☐	**4** ☐	**5** ☐
Sill plates	**0** ☐	**1** ☐	**2** ☐	**3** ☐	**4** ☐	**5** ☐
Kitchen cabinets	**0** ☐	**1** ☐	**2** ☐	**3** ☐	**4** ☐	**5** ☐
Bathroom cabinets	**0** ☐	**1** ☐	**2** ☐	**3** ☐	**4** ☐	**5** ☐
Fencing	**0** ☐	**1** ☐	**2** ☐	**3** ☐	**4** ☐	**5** ☐
Molding	**0** ☐	**1** ☐	**2** ☐	**3** ☐	**4** ☐	**5** ☐

Ready-to-assemble furniture **0** ☐ **1** ☐ **2** ☐ **3** ☐ **4** ☐ **5** ☐

5. Please rate the amount of **your knowledge** and **past experience** with woodfiber-plastic composites used in building applications on the appropriate scale. *(Click on the box next to the selected number for each scale.)*

NO KNOWLEDGE					*MUCH* KNOWLEDGE	*NO* EXPERIENCE					*MUCH* EXPERIENCE
0 ☐	**1** ☐	**2** ☐	**3** ☐	**4** ☐	**5** ☐	**0** ☐	**1** ☐	**2** ☐	**3** ☐	**4** ☐	**5** ☐
		KNOWLEDGE						**EXPERIENCE**			

6a. How many trade or professional associations are you a member of *(Please click only one box and exclude those associations that are not specifically construction or building related)*?

Number of Trade or Professional Association Memberships

☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 or more

6b. Please list the names of the professional and trade association(s) that you are a member of?

1.
2.
3.
4.
5.

7a. How many conferences/seminars related to building materials did you attend in 2000 and 2001 *(Please circle only one number and exclude those conferences/seminars that are not specifically construction or building related)*?

Number of Conferences/Seminars Attended

0 1 2 3 4 5 or more

7b. Please list the name(s) of the conferences(s)/seminar(s) related to building materials that you attended in 2000 and 2001?

____

____

8a. Estimate the number of building material trade shows that members of your company attended in 2000 and 2001 *(Please circle only one number).*

Number of Building Material Trade Shows Organization Attended

0 1 2 3 4 5 or more

8b. Please list the name(s) of the building material trade show(s) that your company attended?

____

____

9a. Please rate how important the following factors are for the Navy in learning about new building materials. *(Circle one number for each factor).*

	No Importance					**Critically Important**
Factors	0	1	2	3	4	5
Conferences/seminars	0	1	2	3	4	5
Government research	0	1	2	3	4	5
Advertisements of material manufacturers	0	1	2	3	4	5
Trade show exhibits	0	1	2	3	4	5
Direct mail	0	1	2	3	4	5

	0	1	2	3	4	5
Trade/industry journals	0	1	2	3	4	5
Media promotion	0	1	2	3	4	5
Opinions of peers	0	1	2	3	4	5
Other, please specify___________________	0	1	2	3	4	5
___________________	0	1	2	3	4	5

9b. If you circled any number other than "0" for "Opinions of peers", please specify who are your peer groups?

____

____

10. Please indicate the magnitude of your role in the **selection** and **purchase** of new and replacement building materials?

BUILDING MATERIALS	**NEW** NO INFLUENCE					MUCH INFLUENCE	**REPLACEMENT** NO INFLUENCE					MUCH INFLUENCE
Selection	**0** ☐	**1** ☐	**2** ☐	**3** ☐	**4** ☐	**5** ☐	**0** ☐	**1** ☐	**2** ☐	**3** ☐	**4** ☐	**5** ☐
Purchase	**0** ☐	**1** ☐	**2** ☐	**3** ☐	**4** ☐	**5** ☐	**0** ☐	**1** ☐	**2** ☐	**3** ☐	**4** ☐	**5** ☐

11. Please rate how important the following perceived benefits are for the Navy in adopting new building materials. *(Circle one number for each perceived benefit).*

	No Importance				**Critically Important**	
Perceived benefits	0	1	2	3	4	5
Affordability	0	1	2	3	4	5
Durability	0	1	2	3	4	5
Safety (reduced risk)	0	1	2	3	4	5
Reduced liability	0	1	2	3	4	5
Environmentally friendly (Green)	0	1	2	3	4	5
Aesthetics	0	1	2	3	4	5
Ease of installation	0	1	2	3	4	5
Other, please specify ___________________	0	1	2	3	4	5
___________________	0	1	2	3	4	5

ORGANIZATION SECTION

12. What is your current position?
☐ Structural Engineer ☐ Facilities Maintenance Supervisors ☐ Facility Maintenance Specialists
☐ Other – *please specify*

13. What is your age?
☐ 22 and under ☐ 23-32 ☐ 33-42 ☐ 43-52 ☐ 53 and over

14. What is the highest level of education that you completed?
☐ Did not complete high school ☐ Completed high school or equivalent ☐ Some college or post high school training
☐ Completed college degree ☐ Graduate or professional training beyond college degree

15. Most PURCHASING decisions for BUILDING MATERIALS for my unit are made by:
☐ self ☐ Officer in charge of construction – ROICC ☐ Other (please specify title)

16. Most SELECTION decisions for BUILDING MATERIALS for my unit are made by:
☐ self ☐ Officer in charge of construction – ROICC ☐ Other (please specify title)

17. For 2001, please provide your best estimate of the number of personnel at facilities under your jurisdiction including tenant commands involved in:

 # OF PERSONNEL

(a) Maintenance and repair of facilities
(b) Construction administration
(c) Specifying & selecting construction materials

18. Please estimate the dollar value of ALL repair/maintenance and construction at facilities under your jurisdiction including the maintenance and repair costs born by your tenant commands for 2001.

(TOTAL $ of repair/maintenance) (TOTAL $ of construction)

19. Do you have any other comments/opinions that relate to material usage and factors influencing the selection/purchase of BUILDING MATERIALS IN GENERAL, and or WOODFIBER-PLASTIC COMPOSITES.

THANKS FOR YOUR HELP! Please save this form and attach it to an email to
Theresa Hoffard at hoffardta@nfesc.navy.mil **and Kimberly Del Bright at** mailto:kdb9@psu.edu
Your response has ensured that this study will be a success.

Appendix 7: Prime Contractor Questionnaire

STUDY OF NEW MATERIALS FOR BUILDING APPLICATIONS

THE PENNSYLVANIA STATE UNIVERSITY
NAVAL FACILITIES ENGINEERING COMMAND
OFFICE OF NAVAL RESEARCH
WASHINGTON STATE UNIVERSITY

REFERENCE INFORMATION

You have been selected for this survey because of your firm's construction work for the Navy. Your answers to these questions are needed to develop materials with improved performance. In the following sections, you are asked to give your opinion of durability issues, substitution potential, and use of materials in building applications. This survey should take approximately 10 to 15 minutes to complete, and all answers are strictly confidential.

We thank you for your cooperation and would like to know your preferences for our tokens of appreciation for completing this survey.

Please check your preferences:

______I would like to receive a summary of the study results.

______I would like to be entered into the raffle for the embroidered PSU sweatshirt. *Please circle the sweatshirt size you prefer: (Small Medium Large Extra large)*

- **Have you participated in building material selection or purchase within the last five years for your firm?**

  YES
  NO

(If "NO," please give this to the appropriate person in your organization. If "YES," please turn the page and go to question 1.)

1. Considering your building material experience, please specify the three building components and their associated type of durability problem that occur with the greatest frequency.

BUILDING COMPONENT	TYPE OF DURABILITY PROBLEM*
1.______________________	__________________________
2.______________________	__________________________

3.______________________ _________________________

*Studies show that the major <u>types of durability problems</u> for building components are the result of damage from:

- Moisture (expansion and warping)
- Fungal decay
- Mold
- Poor retention of finish (paint, stain)
- Insect (mainly termites)
- Weathering (UV from sunlight, surface erosion)
- Mechanical stresses (other than wind or earthquake)
- Poor design
- Improper installation
- Fire
- Structural overload (wind, hurricanes, tornadoes, and earthquakes)

2. What are your perceptions of the durability of the following general applications? Rate each application with 0 = low durability to 5 = high durability. For all the applications that you rate lower than 3, please indicate the <u>type of durability problem</u> that is the major reason for the failure mode. You may wish to refer to the types of durability problems listed above. *(Circle one number for each application)*

APPLICATIONS	**LOW DURABILITY**					**HIGH DURABILITY**	**For applications rated <u>lower than</u> 3, please indicate the type of durability problem**
Wall framing	**0**	**1**	**2**	**3**	**4**	**5**	______________________
I joists	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Beams/headers	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Roofing	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Roof trusses	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Roof sheathing	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Floor underlayment	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Interior doors	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Exterior door framing	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Window lineals	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Siding	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Fascia, soffit, & corners	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Deck boards/stair treads	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Deck railing systems	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Sill plates	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Kitchen cabinets	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Bathroom cabinets	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Fencing	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Moldings	**0**	**1**	**2**	**3**	**4**	**5**	______________________
<u>Additional applications</u>							
(*If not listed above*)							
a. ___________	**0**	**1**	**2**	**3**	**4**	**5**	______________________
b. ___________	**0**	**1**	**2**	**3**	**4**	**5**	______________________
c. ___________	**0**	**1**	**2**	**3**	**4**	**5**	______________________

For the purposes of this questionnaire, woodfiber-plastic composites (WPC) are defined as a composite material made of wood combined with plastic.

3. Carefully read each of the ***Product Use Phrases*** listed below. Please indicate next to each of the particular products which ***Product Use Phrase*** most closely describes your company's use of that particular product. Please answer for all eleven products.

EXAMPLE: If your firm is familiar with precast concrete insulated wall panels but has never used them, then you would circle a “2” on the number line next to the precast concrete insulated wall panels.

Product Use Phrases:
1 = Not familiar at all with <u>(product)</u>
2 = Our firm is familiar with <u>(product)</u> but has never used it
3 = Our firm is currently using <u>(product)</u> but only on a trial basis
4 = Our firm is routinely using <u>(product)</u>

If your firm has used <u>(product)</u> but later stopped using it altogether, please check the column labeled “*Firm used product but has stopped,”* and please provide a brief explanation of why your firm stopped using the product on the space provided.

	Product Use Phrase Number	***Firm used product but has stopped***	***Reason why no longer using prod.***
Precast concrete insulated wall panels (basement/crawl spaces)	**1 2 3 4**		
Preassembled wall sections (e.g., structural insulated panels)			
Laminated veneer lumber (LVL) beams/headers			
Laminated veneer lumber (LVL) I-joists			
Wood trusses (versus rafters)			
Fibre cement siding			
Woodfiber-plastic composite (WPC) outdoor decking (i.e. Trex, Weatherbest, etc.)			
Woodfiber-plastic composite (WPC) railings for decking (i.e. Trex, etc.)			
Woodfiber-plastic composite (WPC) windows (i.e., Anderson’s Renewal®)			
Woodfiber-plastic composite (WPC) exterior door sills (i.e., AERT Moisture Shield®)			
Structural composite lumber (i.e., Parallam®, Timberstrand®)			
Light gauge steel framing			

Please be certain that you rated all products!

4. Beside each of the wood products listed below, please indicate the year that your company first used the product. If your company has never used the product, please leave the line blank.

	Year of First Use		**Year of First Use**
Precast concrete insulated wall panels (basement/crawl spaces)	________	Fiber cement siding	________
Preassembled wall sections (e.g., structural insulated panels)	________	WPC outdoor decking	________
LVL beams/headers	________	WPC railing for decking	________
LVL I-joists	________	WP C windows	________
Wood trusses	________	WPC exterior door framing	________
Structural composite lumber	________	Light gauge steel framing	________

5. Please rate how important the following perceived benefits are for your company in adopting new building materials. *(Circle one number for each perceived benefit)*

	No Importance					**Critically Important**
Perceived benefits	0	1	2	3	4	5
Affordability	0	1	2	3	4	5
Durability	0	1	2	3	4	5
Safety (reduced risk)	0	1	2	3	4	5
Reduced liability	0	1	2	3	4	5
Environmentally friendly (Green)	0	1	2	3	4	5
Aesthetics	0	1	2	3	4	5
Ease of installation	0	1	2	3	4	5
Other, please specify __________________	0	1	2	3	4	5
__________________	0	1	2	3	4	5

6. Please rate the amount of **your knowledge** and **past experience** with woodfiber-plastic composites used in building applications on the appropriate scale. *(Circle one number for each scale)*

No KNOWLEDGE — **much** KNOWLEDGE

0 1 2 3 4 5

KNOWLEDGE

No EXPERIENCE — **much** EXPERIENCE

0 1 2 3 4 5

EXPERIENCE

7. What are your perceptions of the **CURRENT SUBSTITUTION POTENTIAL** of woodfiber-plastic composites when

used in the following building applications? Consider physical (durability, shrink-swell etc.), and mechanical (structural strength, stiffness, etc.), requirements for each application in addition to cost issues. Rate each application with 0 = no potential to 5 = the most potential. Please check "*Don't know*" if you are uncertain. *(Circle one number for each application)*

APPLICATIONS	NO POTENTIAL 0	1	2	3	4	MOST POTENTIA 5	Don't Know
Wall framing	**0**	**1**	**2**	**3**	**4**	**5**	_____
I joists	**0**	**1**	**2**	**3**	**4**	**5**	
Beams/headers	**0**	**1**	**2**	**3**	**4**	**5**	
Roofing	**0**	**1**	**2**	**3**	**4**	**5**	
Roof trusses	**0**	**1**	**2**	**3**	**4**	**5**	
Roof sheathing	**0**	**1**	**2**	**3**	**4**	**5**	
Floor underlayment	**0**	**1**	**2**	**3**	**4**	**5**	
Interior doors	**0**	**1**	**2**	**3**	**4**	**5**	
Exterior door framing	**0**	**1**	**2**	**3**	**4**	**5**	
Window lineals	**0**	**1**	**2**	**3**	**4**	**5**	
Siding	**0**	**1**	**2**	**3**	**4**	**5**	
Fascia, soffit, & corners	**0**	**1**	**2**	**3**	**4**	**5**	
Deck boards/stair treads	**0**	**1**	**2**	**3**	**4**	**5**	
Deck railing systems	**0**	**1**	**2**	**3**	**4**	**5**	
Sill plates	**0**	**1**	**2**	**3**	**4**	**5**	
Kitchen cabinets	**0**	**1**	**2**	**3**	**4**	**5**	
Bathroom cabinets	**0**	**1**	**2**	**3**	**4**	**5**	
Fencing	**0**	**1**	**2**	**3**	**4**	**5**	
Moldings	**0**	**1**	**2**	**3**	**4**	**5**	
Ready-to-assemble furniture	**0**	**1**	**2**	**3**	**4**	**5**	
Additional applications (*If not listed above*)							
a. ___________	**0**	**1**	**2**	**3**	**4**	**5**	
b. ___________	**0**	**1**	**2**	**3**	**4**	**5**	
c. ___________	**0**	**1**	**2**	**3**	**4**	**5**	

Finally, we would like some information about you and your company for statistical purposes. **All identifying information (personal names, company names, and locations) is removed for the analysis of the data. YOU CAN BE ASSURED OF COMPLETE CONFIDENTIALITY.**

8. Approximately how many years has your company been involved in the nonresidential construction industry?
________years

9. Approximately how many of the following types of structures did your company complete in 2001?
_________Residential structures
_________Nonresidential structures

10. Approximately what were your company's total sales in 2001? *(Please check only one)*
- ❑ 0 - $1,000,000
- ❑ $1,000,001 to $10,000,000
- ❑ $10,000,001 to $15,000,000
- ❑ $15,000,001 to $20,000,000
- ❑ $20,000,001 to $25,000,000
- ❑ Over $25,000,000

11. For 2001, approximately what percentage of your company's sales revenue was generated from the following activities?

(d) Residential Construction _________________%
(e) Nonresidential Construction _________________%
(f) Maintenance and repair _________________%
(g) Other (please specify below) _________________%

Total = 100%

12. Does your company conduct business in multiple states? YES NO If YES, how many states?________

13. In which state does your company generate its greatest amount of revenue? ______________________________

14. Estimate the number of building material trade shows that members of your company attended in 2000 and 2001 *(Please circle only one number).*

Number of Building Material Trade Shows Organization Attended

0 1 2 3 4 5 or more

14b. Please list the name(s) of the building material trade show(s) that your company attended?

____
____

15. Please rate how important the following factors are for your company in learning about new building materials. *(Circle one number for each factor)*

Factors	**0** (No Importance)	**1**	**2**	**3**	**4**	**5** (Critically Important)
Conferences/seminars	0	1	2	3	4	5
Government research	0	1	2	3	4	5
Advertisements of material manufacturers	0	1	2	3	4	5
Trade show exhibits	0	1	2	3	4	5
Direct mail	0	1	2	3	4	5
Trade/industry journals	0	1	2	3	4	5
Media promotion (i.e.,"This Old House")	0	1	2	3	4	5
Opinions of peers	0	1	2	3	4	5
Other, please specify _________________	0	1	2	3	4	5
_________________	0	1	2	3	4	5

15a. If you circled any number other than "0" for "Opinions of peers", please specify who are your peer groups?

____
____

16. How many trade or professional associations are you a member of *(Please circle only one number and exclude those associations that are not specifically construction or building related)*?

Number of Trade or Professional Association Memberships

0 1 2 3 4 5 or more

16b. Please list the names of the professional and trade association(s) that you are a member of?

____
____
____
____

17. How many conferences/seminars related to building materials did you attend in 2000 and 2001 *(Please circle only one number and exclude those conferences/seminars that are not specifically construction or building related)*?

Number of Conferences/Seminars Attended

0 1 2 3 4 5 or more

17b. Please list the name(s) of the conferences(s)/seminar(s) related to building materials that you attended in 2000 and 2001?

____

____

18. How many trade/industry journals concerning building materials do you read on a regular basis *(Please circle only one number)?*

Number of Trade/Industry Journals Read (Regularly)

0 1 2 3 4 5 or more

18b. What trade/industry journals do you read on a regular basis?

____

____

19. Please indicate the magnitude of your role in the **selection** and **purchase** of new building materials?

	NEW					
BUILDING MATERIALS	NO INFLUENCE				MUCH INFLUENCE	
Selection	**0**	**1**	**2**	**3**	**4**	**5**
Purchase	**0**	**1**	**2**	**3**	**4**	**5**

20. What is your age?
( ) 22 and under ( ) 23-32 ( ) 33-42 ( ) 43-52 ( ) 53 and over

21. What is the highest level of education that you completed?
( ) Did not complete high school ( ) Completed high school or equivalent ( ) Some college or post high school training
( ) Completed college degree ( ) Graduate or professional training beyond college degree

22. How many years have you been with the company? _______years

23. Do you have any other comments/opinions that relate to material usage and factors influencing the selection/purchase of BUILDING MATERIALS IN GENERAL and or WOODFIBER-PLASTIC COMPOSITES?

____

____

____

THANKS FOR YOUR HELP!
Please return this postage paid survey by taping it closed and dropping it in the nearest mailbox. Your response has ensured that this study will be a success.

Appendix 8: "Top 200+" Builders Questionnaire

PENNSTATE

STUDY OF NEW MATERIALS FOR BUILDING APPLICATIONS

THE PENNSYLVANIA STATE UNIVERSITY

REFERENCE INFORMATION

You have been selected for this survey because of your firm's status as a leader in the building industry. Your answers to these questions are needed to develop materials with improved performance. In the following sections, you are asked to give <u>your opinion</u> of durability issues, substitution potential, and use of materials in building applications. This survey should take approximately 10 to 15 minutes to complete, and all answers are <u>strictly confidential</u>.

We thank you for your cooperation and would like to know your preferences for our tokens of appreciation for completing this survey.

Please check your preferences:

______I would like to receive a summary of the study results.

______I would like to be entered into the raffle for the embroidered PSU sweatshirt. *Please circle the sweatshirt size you prefer: (Small Medium Large Extra large)*

- **Have you participated in building material selection or purchase within the last five years for your firm?**

YES

NO

(If "NO," please give this to the appropriate person in your organization. If "YES," please turn the page and go to question 1.)

1. Considering your building material experience, please specify the three building components and their associated type of durability problem that occur with the greatest frequency.

BUILDING COMPONENT	**TYPE OF DURABILITY PROBLEM***
A.______________________	__________________________
B.______________________	__________________________
C.______________________	__________________________

*Studies show that the major types of durability problems for building components are the result of damage from:

- Moisture (expansion and warping)
- Fungal decay
- Mold
- Poor retention of finish (paint, stain)
- Insect (mainly termites)
- Weathering (UV from sunlight, surface erosion)
- Mechanical stresses (other than wind or earthquake)
- Poor design
- Improper installation
- Fire
- Structural overload (wind, hurricanes, tornadoes, and earthquakes)

2. What are your perceptions of the durability of the following general applications? Rate each application with 0 = low durability to 5 = high durability. For all the applications that you rate lower than 3, please indicate the type of durability problem that is the major reason for the failure mode. You may wish to refer to the types of durability problems listed above. *(Circle one number for each application)*

APPLICATIONS	**LOW DURABILITY**					**HIGH DURABILITY**	**For applications rated lower than 3, please indicate the type of durability problem**
Wall framing	**0**	**1**	**2**	**3**	**4**	**5**	______________________
I joists	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Beams/headers	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Roofing	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Roof trusses	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Roof sheathing	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Floor underlayment	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Interior doors	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Exterior door framing	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Window lineals	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Siding	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Fascia, soffit, & corners	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Deck boards/stair treads	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Deck railing systems	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Sill plates	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Kitchen cabinets	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Bathroom cabinets	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Fencing	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Moldings	**0**	**1**	**2**	**3**	**4**	**5**	______________________
Additional applications (*If not listed above*)							
a. ___________	**0**	**1**	**2**	**3**	**4**	**5**	______________________

b. ___________ 0 1 2 3 4 5 ____________________________
c. ___________ 0 1 2 3 4 5 ____________________________

For the purposes of this questionnaire, woodfiber-plastic composites (WPC) are defined as a composite material made of wood combined with plastic.

3. Carefully read each of the ***Product Use Phrases*** listed below. Please indicate next to each of the particular products which ***Product Use Phrase*** most closely describes your company's use of that particular product. Please answer for all eleven products.

   EXAMPLE: If your firm is familiar with precast concrete insulated wall panels but has never used them, then you would circle a "2" on the number line next to the precast concrete insulated wall panels.

   Product Use Phrases:
   1 = Not familiar at all with (product)
   2 = Our firm is familiar with (product) but has never used it
   3 = Our firm is currently using (product) but only on a trial basis
   4 = Our firm is routinely using (product)
   5 = Our firm used (product) but has stopped

   If your firm has used (product) but later stopped using it altogether, please check the column labeled "*Firm used product but has stopped,*" and please provide a brief explanation of why your firm stopped using the product on the space provided.

	Product Use Phrase Number	***Firm used product but has stopped***	***Reason why no longer using product***
Precast concrete insulated wall panels (basement/crawl spaces)	**1 2 3 4**	**5**	
Preassembled wall sections (e.g., structural insulated panels)			
Laminated veneer lumber (LVL) beams/headers			
Laminated veneer lumber (LVL) I-joists			
Wood trusses (versus rafters)			
Fibre cement siding			
Woodfiber-plastic composite (WPC) outdoor decking (i.e. Trex, Weatherbest, etc.)			
Woodfiber-plastic composite (WPC) railings for decking (i.e. Trex, etc.)			
Woodfiber-plastic composite (WPC) windows (i.e., Anderson's Renewal®)			
Woodfiber-plastic composite (WPC) exterior door sills (i.e., AERT Moisture Shield®)			
Structural composite lumber (i.e., Parallam®, Timberstrand®)			
Light gauge steel framing			

Please be certain that you rated all products!

4. Beside each of the wood products listed below, please indicate the year that your company first used the product. If your company has never used the product, please leave the line blank.

	Year of First Use		Year of First Use
Precast concrete insulated wall panels (basement/crawl spaces)	________	Fiber cement siding	________
Preassembled wall sections (e.g., structural insulated panels)	________	WPC outdoor decking	________
LVL beams/headers	________	WPC railing for decking	________
LVL I-joists	________	WP C windows	________
Wood trusses	________	WPC exterior door framing	________
Structural composite lumber	________	Light gauge steel framing	________

5. Please rate how important the following perceived benefits are for your company in adopting new building materials. *(Fill in one circle for each perceived benefit)*

	No Importance					Critically Important
Perceived benefits	0	1	2	3	4	5
Affordability	0	1	2	3	4	5
Durability	0	1	2	3	4	5
Safety (reduced risk)	0	1	2	3	4	5
Reduced liability	0	1	2	3	4	5
Environmentally friendly (Green)	0	1	2	3	4	5
Aesthetics	0	1	2	3	4	5
Ease of installation	0	1	2	3	4	5
Other, please specify ________________	0	1	2	3	4	5
________________	0	1	2	3	4	5

6. Please rate the amount of **your knowledge** and **past experience** with woodfiber-plastic composites used in building applications on the appropriate scale. *(Circle one number for each scale)*

NO *MUCH* *NO* *MUCH*

KNOWLEDGE KNOWLEDGE EXPERIENCE EXPERIENCE

0 1 2 3 4 5 **0 1 2 3 4 5**

KNOWLEDGE EXPERIENCE

7. What are your perceptions of the **CURRENT SUBSTITUTION POTENTIAL** of woodfiber-plastic composites when used in the following building applications? Consider physical (durability, shrink-swell etc.), and mechanical (structural strength, stiffness, etc.), requirements for each application in addition to cost issues. Rate each application with 0 = no potential to 5 = the most potential. Please check "*Don't know*" if you are uncertain. *(Circle one number for each application)*

APPLICATIONS	NO POTENTIAL					MOST POTENTIAL	Don't Know
Wall framing	**0**	**1**	**2**	**3**	**4**	**5**	_____
I joists	**0**	**1**	**2**	**3**	**4**	**5**	
Beams/headers	**0**	**1**	**2**	**3**	**4**	**5**	
Roofing	**0**	**1**	**2**	**3**	**4**	**5**	
Roof trusses	**0**	**1**	**2**	**3**	**4**	**5**	
Roof sheathing	**0**	**1**	**2**	**3**	**4**	**5**	

Floor underlayment	**0**	**1**	**2**	**3**	**4**	**5**
Interior doors	**0**	**1**	**2**	**3**	**4**	**5**
Exterior door framing	**0**	**1**	**2**	**3**	**4**	**5**
Window lineals	**0**	**1**	**2**	**3**	**4**	**5**
Siding	**0**	**1**	**2**	**3**	**4**	**5**
Fascia, soffit, & corners	**0**	**1**	**2**	**3**	**4**	**5**
Deck boards/stair treads	**0**	**1**	**2**	**3**	**4**	**5**
Deck railing systems	**0**	**1**	**2**	**3**	**4**	**5**
Sill plates	**0**	**1**	**2**	**3**	**4**	**5**
Kitchen cabinets	**0**	**1**	**2**	**3**	**4**	**5**
Bathroom cabinets	**0**	**1**	**2**	**3**	**4**	**5**
Fencing	**0**	**1**	**2**	**3**	**4**	**5**
Moldings	**0**	**1**	**2**	**3**	**4**	**5**
Ready-to-assemble furniture	**0**	**1**	**2**	**3**	**4**	**5**
Additional applications (*If not listed above*)						
a. ___________	**0**	**1**	**2**	**3**	**4**	**5**
b. ___________	**0**	**1**	**2**	**3**	**4**	**5**
c. ___________	**0**	**1**	**2**	**3**	**4**	**5**

8. For the statements below, please indicate your level of agreement or disagreement with the following statements by circling the single most appropriate number for each statement. Please rate the following questions with 7 = strongly agree, 4 = neutral, and 1 = strongly disagree.

	Strongly Disagree						Strongly Agree
My company would like to use a new product today, if possible.	1	2	3	4	5	6	7
We are likely to be one of the first companies to use a new product	1	2	3	4	5	6	7
My company likes to take chances with new products.	1	2	3	4	5	6	7
My company likes to experiment with new ways of doing things.	1	2	3	4	5	6	7
New products are usually gimmicks.	1	2	3	4	5	6	7
My company finds it difficult to change established construction procedures to cater to the needs of a new product.	1	2	3	4	5	6	7
My company can easily change our building practices to fit the needs of a new product.	1	2	3	4	5	6	7
My company is slow to detect fundamental shifts in our industry (e.g., competition, technology, regulation).	1	2	3	4	5	6	7
My company is oriented more toward the future than the present.	1	2	3	4	5	6	7
Many of our building practices cannot be applied to new products.	1	2	3	4	5	6	7
Our current marketing abilities are not very useful in marketing homes that use new products.	1	2	3	4	5	6	7
Our relationships with current suppliers is more important than using a new product.	1	2	3	4	5	6	7

Finally, we would like some information about you and your company for statistical purposes. **All identifying information (personal names, company names, and locations) is removed for the analysis of the data. YOU CAN BE ASSURED OF COMPLETE CONFIDENTIALITY.**

9. For 2001, approximately what percentage of your company's sales revenue was generated from the following activities?

(h) Residential Construction _________________%
(i) Nonresidential Construction _________________%
(j) Maintenance and repair _________________%
(k) Other (please specify below) _________________%
_________________ **Total = 100%**

10. Does your company conduct business in multiple states? YES NO If YES, how many states?________

11. In which state does your company generate its greatest amount of revenue? ______________________________

12. Please rate how important the following factors are for your company in learning about new building materials. *(Circle one number for each factor)*

Factors	**No Importance** 0	1	2	3	4	**Critically Important** 5
Conferences/seminars	0	1	2	3	4	5
Government research	0	1	2	3	4	5
Advertisements of material manufacturers	0	1	2	3	4	5
Trade show attendance *(see 12a)*	0	1	2	3	4	5
Direct mail	0	1	2	3	4	5
Trade/industry journals *(see 12b)*	0	1	2	3	4	5
Media promotion (i.e.,"This Old House")	0	1	2	3	4	5
Opinions of peers *(see 12c)*	0	1	2	3	4	5
Customers (homeowners)	0	1	2	3	4	5
Current building material suppliers	0	1	2	3	4	5
Other, please specify ________________	0	1	2	3	4	5
________________	0	1	2	3	4	5

12a. If you circled any number other than "0" for "Trade show attendance", please specify which trade shows.

____

____

12b. If you circled any number other than "0" for "Trade/industry journals", please specify which journals.

____

____

12c. If you circled any number other than "0" for "Opinions of peers", please specify who are your peer groups.

____

____

13a. How many trade or professional associations are you a member of *(Please circle only one number and exclude those associations that are not specifically construction or building related)*?

Number of Trade or Professional Association Memberships

0	1	2	3	4	5 or more

13b. Please list the names of the professional and trade association(s) that you are a member of?

____

____

____

____

14. Please indicate the magnitude of <u>your role</u> in the **selection** and **purchase** of building materials?

BUILDING MATERIALS	NO INFLUENCE					MUCH INFLUENCE
Selection	**0**	**1**	**2**	**3**	**4**	**5**
Purchase	**0**	**1**	**2**	**3**	**4**	**5**

15. What is your job title?

____

16. What is your age?
( ) 22 and under ( ) 23-32 ( ) 33-42 ( ) 43-52 ( ) 53 and over

17. What is the highest level of education that you completed?
( ) Did not complete high school ( ) Completed high school or equivalent ( ) Some college or post high school training
( ) Completed college degree ( ) Graduate or professional training beyond college degree

18. How many years have you been with the company? _______years

19. Do you have any other comments/opinions that relate to material usage and factors influencing the selection/purchase of BUILDING MATERIALS IN GENERAL and or WOODFIBER-PLASTIC COMPOSITES?

____
____
____

THANKS FOR YOUR HELP!
Please return this postage paid survey by taping it closed and dropping it in the nearest mailbox. Your response has ensured that this study will be a success.

Appendix 9: Distributor/Retailer Questionnaire

STUDY OF NEW MATERIALS FOR BUILDING APPLICATIONS

THE PENNSYLVANIA STATE UNIVERSITY

REFERENCE INFORMATION

You have been selected for this survey because of your company's purchase and distribution of building materials. Your answers to these questions are needed to better understand wholesalers' perceptions of new products. In the following sections, you are asked to give your opinion on the following: customer complaints with certain types of products, familiarity with different products, and factors that impact your company's decision to carry new products. This survey should take approximately 10 to 15 minutes to complete, and all answers are strictly confidential.

We thank you for your cooperation and would like to know your preferences for our tokens of appreciation for completing this survey.

Please check your preferences:

______I would like to receive a summary of the study results.

______I would like to be entered into the raffle for the embroidered PSU sweatshirt. *Please circle the sweatshirt size you prefer: (Small Medium Large Extra large)*

- **Have you participated in building material selection or purchase within the last five years for your firm?**

YES

NO

(If "NO," please give this to the appropriate person in your organization. If "YES," please turn the page and go to question 1.)

1. Considering your experience in supplying building materials, please specify the three building components and their associated type of warranty problem that occur with the greatest frequency.

BUILDING MATERIAL	**TYPE OF WARRANTY PROBLEM**
1. ______________________	___________________________

2. ______________________ ________________________

3. ______________________ ________________________

2. What are your perceptions of customer complaints for the following general applications? Please rate each application with 1 = few customer complaints to 5 = many customer complaints. For all the applications that you rate lower than 3, please indicate the type of problem that is the major reason for the complaint.

PRODUCT	FEW COMPLAINTS 0	1	2	3	4	MANY COMPLAINTS 5	**For applications rated lower than 3, please indicate the type of problem with the product.**
Roof sheathing	0	1	2	3	4	5	______________________
Floor underlayment	0	1	2	3	4	5	______________________
Exterior doors	0	1	2	3	4	5	______________________
Windows	0	1	2	3	4	5	______________________
Siding	0	1	2	3	4	5	______________________
Fascia, soffit, & corners	0	1	2	3	4	5	______________________
Deck boards/stair treads	0	1	2	3	4	5	______________________
Deck railing systems	0	1	2	3	4	5	______________________
Sill plates	0	1	2	3	4	5	______________________
Fencing	0	1	2	3	4	5	______________________
Moldings	0	1	2	3	4	5	______________________
Additional applications (*If not listed above*)							
a. ___________	0	1	2	3	4	5	______________________
b. ___________	0	1	2	3	4	5	______________________
c. ___________	0	1	2	3	4	5	______________________

For the purposes of this questionnaire, woodfiber-plastic composites (WPC) are defined as a composite material made of wood combined with plastic.

3. Carefully read each of the ***Product Familiarity Phrases*** listed below. Please indicate next to each of the particular products the ***Product Familiarity Phrase*** that most closely describes your company's familiarity of that particular product. Please answer for all ten products.

EXAMPLE: If your company is familiar with LVL I-joists and fiber cement siding; but has never used them, then you would circle a "2" on the number line next to the precast concrete insulated wall panels.

Product Use Phrases:
1 = Our company is not familiar at all with (product)
2 = Our company is familiar with (product), but has never carried it
3 = Our company is currently carrying (product), but only on a trial basis
4 = Our company is routinely carrying (product)
5 = Our company used (product) but has stopped

If your company has carried (product) but later stopped using it altogether, please check the column labeled "*Company carried product but has stopped,*" and please provide a brief explanation of why your company stopped carrying the product in the space provided.

Product Use ***Company carried product*** ***Reason why***

	Phrase Number	*but has stopped*	*longer using product*
Laminated veneer lumber (LVL) beams/headers	**1 2 3 4**	**5**	
Laminated veneer lumber (LVL) I-joists			
Wood trusses (versus rafters)			
Fiber cement siding			
Woodfiber-plastic composite (WPC) outdoor decking (i.e. Trex, Weatherbest, etc.)			
Woodfiber-plastic composite (WPC) railings for decking (i.e. Trex, etc.)			
Woodfiber-plastic composite (WPC) windows (i.e., Anderson's Renewal®)			
Woodfiber-plastic composite (WPC) exterior door sills (i.e., AERT Moisture Shield®)			
Structural composite lumber (i.e., Parallam®, Timberstrand®)			
Light gauge steel framing			

Please be certain that you rated all products!

4. Beside each of the wood products listed below, please indicate the year that your company first carried the product. If your company has
 never carried the product, please leave the line blank.

	Year of First Use		Year of First Use
WPC outdoor decking	________	LVL beams/headers	________
WPC railing for decking	________	LVL I-joists	________
WPC windows	________	Wood trusses	________
WPC exterior door framing	________	Fiber cement siding	________
Structural composite lumber	________	Light gauge steel framing	________
Other WPC product ________	________		

5. Please rate how important the following factors are for your company in adopting new building materials. *(Circle one number for each factor)*

	No Importance					**Critically Important**
Perceived benefits	**0**	**1**	**2**	**3**	**4**	**5**
Increasing Merchandise Breadth	0	1	2	3	4	5
Sales Growth	0	1	2	3	4	5
Profit Growth	0	1	2	3	4	5
Material Handling Processes	0	1	2	3	4	5
Inventorying and Storage Costs	0	1	2	3	4	5
Inventory Turnover Risks	0	1	2	3	4	5
Relationship with Suppliers	0	1	2	3	4	5
Competition	0	1	2	3	4	5
Other, please specify ________________	0	1	2	3	4	5

6. Please rate the amount of **your knowledge** and **past experience** with woodfiber-plastic composites used in building applications on the appropriate scale. *(Circle one number for each scale)*

NO MUCH KNOWLEDGE					MUCH KNOWLEDGE
0	**1**	**2**	**3**	**4**	**5**

KNOWLEDGE

NO EXPERIENCE					MUCH EXPERIENCE
0	**1**	**2**	**3**	**4**	**5**

EXPERIENCE

7. What are your perceptions of the **CURRENT SUBSTITUTION POTENTIAL** of woodfiber-plastic composites when used in the following building applications? Consider physical (durability, shrink-swell etc.), and mechanical (structural strength, stiffness, etc.), requirements for each application in addition to cost issues. Rate each application with 0 = no potential to 5 = the most potential. Please check "*Don't know*" if you are uncertain. *(Circle one number for each application)*

APPLICATIONS	NO POTENTIAL 0	1	2	3	4	MOST POTENTIAL 5	Don't Know
Wall framing	0	1	2	3	4	5	_____
I joists	0	1	2	3	4	5	_____
Beams/headers	0	1	2	3	4	5	_____
Roofing	0	1	2	3	4	5	_____
Roof trusses	0	1	2	3	4	5	_____
Roof sheathing	0	1	2	3	4	5	_____
Floor underlayment	0	1	2	3	4	5	_____
Interior doors	0	1	2	3	4	5	_____
Exterior door framing	0	1	2	3	4	5	_____
Window lineals	0	1	2	3	4	5	_____
Siding	0	1	2	3	4	5	_____
Fascia, soffit, & corners	0	1	2	3	4	5	_____
Deck boards/stair treads	0	1	2	3	4	5	_____
Deck railing systems	0	1	2	3	4	5	_____
Sill plates	0	1	2	3	4	5	_____
Kitchen cabinets	0	1	2	3	4	5	_____
Bathroom cabinets	0	1	2	3	4	5	_____
Fencing	0	1	2	3	4	5	_____
Moldings	0	1	2	3	4	5	_____
Ready-to-assemble furniture	0	1	2	3	4	5	_____
Additional applications (*If not listed above*)							
a. __________________	0	1	2	3	4	5	_____
b. __________________	0	1	2	3	4	5	_____
c. __________________	0	1	2	3	4	5	_____

8. For the statements below, please indicate your level of agreement or disagreement with the following statements by circling the single most appropriate number for each statement. Please rate the following questions with 7 = strongly agree, 4 = neutral, and 1 = strongly disagree.

	Strongly Disagree 1	2	3	4	5	6	Strongly Agree 7
My company would like to carry a new product today, if possible.	1	2	3	4	5	6	7
We are likely to be one of the first companies to carry a new product	1	2	3	4	5	6	7
My company likes to take chances with new products.	1	2	3	4	5	6	7
My company likes to experiment with new ways of doing things.	1	2	3	4	5	6	7
New products are usually gimmicks.	1	2	3	4	5	6	7
My company supports new products even if they could potentially take away from the sales of existing products.	1	2	3	4	5	6	7
My company finds it difficult to change established procedures to cater to the needs of a new product.	1	2	3	4	5	6	7
My company can easily change the manner in which we carry out tasks to fit	1	2	3	4	5	6	7

the needs of a new product.							
My company gives more emphasis to customers of the future, relative to current customers.	1	2	3	4	5	6	7
My company is slow to detect fundamental shifts in our industry (e.g., competition, technology, regulation).	1	2	3	4	5	6	7
My company is oriented more toward the future than the present.	1	2	3	4	5	6	7
Many of our operating skills (i.e. purchasing, material handling, etc) cannot be applied to new products.	1	2	3	4	5	6	7
Our current marketing abilities are not very useful in marketing new products.	1	2	3	4	5	6	7
Our relationships with current suppliers are more important than carrying a new product.	1	2	3	4	5	6	7

Finally, we would like some information about you and your company for statistical purposes. **All identifying information (personal names, company names, and locations) is removed for the analysis of the data. YOU CAN BE ASSURED OF COMPLETE CONFIDENTIALITY.**

9. For 2001, please estimate the percentage of your company's sales revenue generated from the following product types.

Building Material	__________________%
Home Décor/Floor Coverings	__________________%
Hardware	__________________%
Lawn and Garden	__________________%
Paint	__________________%
Other (please specify below)	__________________%
	Total = 100%

9b. Approximately what percentage of your company's purchases were made from the following sources.

Manufacture - Direct	__________________%
Stocking Wholesaler/Distributor	__________________%
Non-Stocking Wholesaler/Distributor	__________________%
Buying Group/Co-op	__________________%
Other (please specify below)	__________________%
	Total = 100%

9c. Please estimate the percent of your company's sales made to each of the following customer types.

Homeowner/End User	__________________%
Builder/Contractor – New Construction	__________________%
Builder/Contractor - Remodel	__________________%
Retailer – DIY Focus	__________________%
Wholesaler/Distributor	__________________%
Other (please specify below)	__________________%
	Total = 100%

10. Does your company conduct business in multiple states? YES NO If YES, how many states?________

11. In which state does your company generate its greatest amount of revenue? ______________________________

12. Please rate how important the following factors are for your company in learning about new building materials. *(Circle one number for each factor)*

No **Critically**

Factors	Importance					Important
	0	1	2	3	4	5
Conferences/seminars	0	1	2	3	4	5
Government research	0	1	2	3	4	5
Advertisements of material manufacturers	0	1	2	3	4	5
Trade show attendance *(see 12a)*	0	1	2	3	4	5
Direct mail	0	1	2	3	4	5
Trade/industry journals *(see 12b)*	0	1	2	3	4	5
Media promotion (i.e.,"This Old House")	0	1	2	3	4	5
Opinions of peers *(see 12c)*	0	1	2	3	4	5
Customers	0	1	2	3	4	5
Current building material suppliers	0	1	2	3	4	5
Other, please specify ________________	0	1	2	3	4	5
________________	0	1	2	3	4	5

12a. If you circled any number other than "0" for "Trade show attendance", please specify which trade shows.

____

____

12b. If you circled any number other than "0" for "Trade/industry journals", please specify which journals.

____

____

12c. If you circled any number other than "0" for "Opinions of peers", please specify who are your peer groups.

____

____

13. What is your job title in your organization? ___________________________

14. What is your age?
( ) 22 and under ( ) 23-32 ( ) 33-42 ( ) 43-52 ( ) 53 and over

15. What is the highest level of education that you completed?
( ) Did not complete high school ( ) Completed high school or equivalent ( ) Some college or post high school training
( ) Completed college degree ( ) Graduate or professional training beyond college degree

16. How many years have you been with the company? _______Years

17. Do you have any other comments/opinions that relate to material usage and factors influencing the selection/purchase of BUILDING MATERIALS IN GENERAL and or WOODFIBER-PLASTIC COMPOSITES?

____

____

____

THANKS FOR YOUR HELP!
Please return this postage paid survey by taping it closed and dropping it in the nearest mailbox. Your response has ensured that this study will be a success.

Appendix 10: LnO Cover Letter

LETTERHEAD
(Date)
(Inside address of respondent)
(Salutation)

Will you do us a favor?

We are conducting a survey to identify the important factors in the selection of materials in the application of windows and doors. This survey is part of a cooperative project with Penn State (State College, PA), Naval Facilities Engineering Service Center (Port Hueneme, CA), Naval Facilities Engineering Command (Washington, DC), and the Office of Naval Research (Arlington, VA),

You are being contacted because you have been identified by the cooperators of this research project as a participant in the selection of materials used for Naval facilities. We are asking for your help. Your responses will be used to direct the development of new materials with improved performance capabilities.

We recognize your time is limited and have made every attempt to make it easy to complete and return. This voluntary survey is designed for easy completion and will take approximately 15 minutes to complete. After you complete this survey, please tape it closed and place it in the mail. We pay the postage.

This survey is **anonymous and completely confidential** and only summary information will be reported in the study results. The number on the cover of this survey is an **identifier only** that allows us to track when we receive your completed survey ensuring that you do not receive subsequent surveys or phone calls.

The information we collect will help those developing new technologies to better understand the decision-making process as well as recognize your concerns as various materials are considered. We would also be pleased to provide you with a **complimentary summary of the study results** as a token of appreciation for completing the survey. Just attach a business card or write your business mailing address inside the back cover of the survey. Or if you wish, you may request a summary of the results by submitting a written request in a separate envelope.

If you have any questions about this research study, I can be reached at (814) 863-3450, or my e-mail address is kdb9@psu.edu. Your help is essential to the study's success.

Sincerely,

Kimberly Del Bright, Penn State University
Project Manager

Appendix 11: LnO Follow Up Letter

PENNSTATE

(814) 863-3450
FAX: (814) 863-7193

School of Forest Resources
College of Agricultural Sciences

The Pennsylvania State University
306 Forest Resources Laboratory
University Park, PA 16802

(Date)
(Inside Address)
(Salutation):

About three weeks ago a questionnaire regarding current and potential new materials used for building applications was mailed to you. Even if you feel that your contribution to this study is minor, it is important that we receive your input. The information we collect will help those developing new building materials to better understand your concerns for new and replacement products.

The number of questionnaires returned is very encouraging. Only a limited number of construction firms are receiving this survey, and whether we will be able to adequately guide product development decisions depends upon you and the others who have not yet responded. This is because our past experiences suggest that those of you who have not yet sent in your questionnaire may have different perceptions of building materials than those who have already responded.

If you have already completed the questionnaire and returned it, please accept our sincere thanks! If not, we urge you to do so today. In case our other correspondence did not reach the person at your firm whose response is needed, a replacement questionnaire is enclosed. Please remember that the survey is anonymous and completely confidential and only summary information will be reported in the study results.

We would also be pleased to provide you with a summary of the study results. Just attach a business card or write your firm's name and mailing address inside the back cover of your completed survey. And there is still time to be entered into the drawing for the comfortable embroidered Penn State sweatshirts!

Your contribution to the success of this study will be greatly appreciated. If you have any questions about the research study, please call me at (814) 863-3450 or my e-mail address is kdb9@psu.edu.

Sincerely,

Kimberly Del Bright, Penn State University
Research Assistant

Appendix 12: LnO Post Card

PENNSTATE

(814) 863-3450
FAX: (814) 863-7193

School of Forest Resources
College of Agricultural Sciences

The Pennsylvania State University
306 Forest Resources Laboratory
University Park, PA 16802

Dear :

Last week a questionnaire regarding current and potential new materials used for window and exterior door applications was mailed to you. Even if you feel that your contribution to this study is small, it is important that we receive your input. Only a limited number of participants in facilities maintenance are receiving this survey. Your input is needed to help develop materials with improved performance capabilities. The information we collect will help those developing new materials to better understand your concerns for new and replacement products.

If you have already completed the questionnaire and returned it, please accept our sincere thanks! If not, we encourage you to do so today. Please remember that the survey is anonymous and completely confidential and only summary information will be reported in the study results. We will be pleased to provide a complimentary summary of the results upon request. Just attach a business card or write your business mailing address inside the back cover of your completed survey.

If you did not receive the questionnaire or misplaced it, please call me at (814) 863-3450, and I will send another one to you today. Thanks for your help!

Sincerely,

Del Bright
Research Assistant

Appendix 13: Prime Contractor Letter

PENNSTATE

(814) 863-3450
FAX: (814) 863-7193

School of Forest Resources
College of Agricultural Sciences

The Pennsylvania State University
305 Forest Resources Laboratory
University Park, PA 16802

24 September 2002

«NAME»
«Contractor»
«Address»
«City», «ST» «ZIP»

Dear «NAME»:

We are conducting a survey to investigate perceptions of current and potential new materials used for building construction. This survey is part of a cooperative project between Penn State, the U.S. Navy [Naval Facilities Engineering Service Center (Port Hueneme, CA) and the Office of Naval Research (Arlington, VA)] and Washington State University.

It is important to solicit opinions from diverse groups of building materials specifiers and users to help expedite the transfer of appropriate innovative research into new products. We have contacted you because our cooperators have identified you as a decision-maker in the selection of building materials used in timber structures.

This voluntary survey is designed for easy completion and will take approximately 10 to 15 minutes of your time. We recognize your time is valuable and have therefore made every attempt to make this easy to fill out and return. After you finish the survey, please tape it closed and place it in the mail. We pay the postage.

This survey if **anonymous and completely confidential** and only summary information will be reported in the study results. The number inside this survey is an **identifier only** that allows us to track when we receive your completed survey ensuring that you do not receive subsequent surveys or phone calls.

The information we collect will help those developing new technologies to better understand the decision-making process as well as recognize your concerns as various materials are considered. We would be pleased to provide you with a **complimentary summary of the study results** as a token of appreciation for completing the survey. Just attach a business card or write your firm's name and mailing address inside the back cover of your completed survey. Or if you wish, you may request a summary of the results by sending a separate written request or by email.

As an additional token of our appreciation for completing the survey, we would like to enter your name in a drawing for a comfortable Penn State sweatshirt with an embroidered PSU logo. (I know this is a bit of a gimmick, but we really do need your help!) If you have any questions about this research study, please call (814) 865-8841 or e-mail me at tdo1@psu.edu. You may also learn more about the project at http://www.composites.wsu.edu/. Your help is essential to the study's success.

Thank you for your time and thoughtful input.

Sincerely,

Tracy Davis O'Connell
Penn State University, Research Assistant

P.S. We have enclosed a Penn State Nittany Lion magnet as a way of saying thanks for your help!

Appendix 14: Prime Contractor Follow Up Letter

PENNSTATE

(814) 863-3450
FAX: (814) 863-7193

School of Forest Resources
College of Agricultural Sciences

The Pennsylvania State University
305 Forest Resources Laboratory
University Park, PA 16802

(Date)
(Inside Address)
(Salutation):

I recently contacted you by phone regarding a questionnaire about current and potential new materials used for building applications. I realize that this is a very busy time of year, but I hope that you will find a few moments to answer this survey. Even if you feel that your contribution to this study is minor, it is important that we receive your input. The information we collect will help those developing new building materials to better understand your concerns for new and replacement products.

Only a limited number of construction firms are receiving this survey, and whether we will be able to adequately guide product development decisions depends upon you and the others who have not yet responded. This is because our past experiences suggest that those of you who have not yet sent in your questionnaire may have different perceptions of building materials than those who have already responded.

If you have already completed the questionnaire and returned it, please accept our sincere thanks! If not, please do so today. In case our previous mailing has been mislaid or lost, a replacement questionnaire is enclosed. Please remember that the survey is anonymous and completely confidential and only summary information will be reported in the study results.

We would be pleased to provide you with a summary of the study results. Just attach a business card or write your firm's name and mailing address inside the back cover of your completed survey. And there is still time to be entered into our "thank you" drawing for a comfortable Penn State sweatshirt with an embroidered PSU logo. We have received more sweatshirts and you now have a one in three chance of winning!

Your contribution to the success of this study will be greatly appreciated. If you have any questions about the research study, please call (814) 865-8841 or e-mail me at tdo1@psu.edu. You may also learn more about the project at http://www.composites.wsu.edu/. Thank you for your time and thoughtful input.

Sincerely,

Tracy Davis O'Connell
Penn State University, Research Assistant

P.S. We have enclosed a Penn State Nittany Lion magnet as a way of saying thanks for your help!

Appendix 15: Prime Contractor Post Card

PENNSTATE

(814) 863-3450
FAX: (814) 863-7193

School of Forest Resources
College of Agricultural Sciences

The Pennsylvania State University
306 Forest Resources Laboratory
University Park, PA 16802

(Salutation):

Last week a questionnaire regarding current and potential new materials used for building applications was mailed to you. Even if you feel that your contribution to this study is small, it is important that we receive your input. Only a limited number of firms are receiving this survey. Your input is needed to help guide product development decisions. The information we collect will help those developing new building materials for the Navy to better understand your concerns for new and replacement products.

If you have already completed the questionnaire and returned it, please accept our sincere thanks! If not, we encourage you to do so today. Please remember that the survey is anonymous and completely confidential and only summary information will be reported in the study results. We will be pleased to provide a complimentary summary of the results upon request. Just attach a business card or write your firm's name and mailing address inside the back cover of your completed survey. And we would also like to enter your name in the drawing for the Penn State sweatshirts!

If you did not receive the questionnaire or misplaced it, please call me at (814) 863-3450, and I will send another one to you today. Thanks for your help!

Sincerely,

Tracy Davis O'Connell
Penn State University, Research Assistant

Appendix 16: "Top 200+" Builders Letter

PENNSTATE

(814) 863-3450
FAX: (814) 863-7193

School of Forest Resources
College of Agricultural Sciences

The Pennsylvania State University
305 Forest Resources Laboratory
University Park, PA 16802

9 November 2002

«CEO»
«COMPANY»
«ADDRESS»

Dear «CEO»:

We are conducting a survey to investigate durability and performance perceptions of current and potential new building materials. It is important to solicit opinions from key builders to better understand factors affecting your selection and purchase of various building materials. We have contacted you because your company is a leading US builder/contractor.

This voluntary survey is designed for easy completion and will take approximately 10 to 15 minutes of your time. We recognize your time is valuable and have therefore made every attempt to make this easy to fill out and return. After you finish the survey, please tape it closed and place it in the mail. We pay the postage. (If you have ***not*** participated in building material or selection or purchase within the last five years, please forward this to an appropriate person in your organization.)

This survey if **anonymous and completely confidential** and only summary information will be reported in the study results. The number inside this survey is an **identifier only** that allows us to track when we receive your completed survey ensuring that you do not receive subsequent surveys or phone calls.

The information we collect will help those developing new technologies/materials/products to better understand your building material perceptions and product use/adoption concerns. We would be pleased to provide you with a **complimentary summary of the study results** as a token of our appreciation for completing the survey. Just attach a business card or write your firm's name and mailing address inside the back cover of your completed survey. Or if you wish, you may request a summary of the results by sending a separate written request or by email.

As an additional token of our appreciation for completing the survey, we would like to enter your name in a drawing for a comfortable Penn State sweatshirt with an embroidered PSU logo. (I know this is a bit of a gimmick, but we really do need your help!) If you have any questions about this research study, please call (814) 865-8841 or e-mail me at tdo1@psu.edu. Your help is essential to the study's success.

Thank you for your time and thoughtful input.

Sincerely,

Tracy Davis O'Connell

Tracy Davis O'Connell
Penn State University, Research Assistant

Appendix 17: "Top 200+" Builders Follow Up Letter

PENNSTATE

(814) 863-3450
FAX: (814) 863-7193

School of Forest Resources
College of Agricultural Sciences

The Pennsylvania State University
305 Forest Resources Laboratory
University Park, PA 16802

2 December 2002

«CEO»
«COMPANY»
«ADDRESS»

Dear «CEO»:

About three weeks ago a questionnaire regarding durability and performance perceptions of current and potential new building materials was mailed to you. Even if you feel that your contribution to this study is minor, it is important that we receive your input. The information that we collect will help those developing new materials to better understand factors affecting your selection and purchase of various building materials.

If you have already completed the questionnaire and returned it, please accept our sincere thanks! If not, we urge you to do so today. In case our other correspondence did not reach the person at your firm whose response is needed, a replacement questionnaire is enclosed. Please remember that the survey is anonymous and completely confidential and only summary information will be reported in the study results.

We would be pleased to provide you with a summary of the study results. Just attach a business card or write your firm's name and mailing address inside the back cover of your completed survey. And there is still time to be entered into the drawing for the comfortable embroidered Penn State sweatshirts!

Your contribution to the success of this study will be greatly appreciated. If you have any questions about the research study, please call (814) 865-8841 or e-mail me at tdo1@psu.edu.

Thank you for your time and thoughtful input.

Sincerely,

Tracy Davis O'Connell

Tracy Davis O'Connell
Research Assistant

Appendix 18: "Top 200+" Builders Post Card

PENNSTATE

(814) 863-3450
FAX: (814) 863-7193

School of Forest Resources
College of Agricultural Sciences

The Pennsylvania State University
305 Forest Resources Laboratory
University Park, PA 16802

18 November 2002

Dear Builder:

Last week a questionnaire regarding durability and performance perceptions of current and potential new building materials was mailed to you. Even if you feel that your contribution to this study is small, it is important that we receive your input. Only a limited number of firms are receiving this survey. Your opinions are needed to help guide product and market development decisions. The information we collect will help those developing new building materials to better understand your concerns for new and replacement products.

If you have already completed the questionnaire and returned it, please accept our sincere thanks! If not, we encourage you to do so today. Please remember that the survey is anonymous and completely confidential and only summary information will be reported in the study results. We will be pleased to provide you with a complimentary summary of the study results upon request. Just attach a business card or write your firm's name and mailing address inside the back cover of your completed survey. And we would also like to enter you name in the drawing for the Penn State sweatshirts!

If you did not receive the questionnaire or misplaced it, please call me at (814) 865-8841 or e-mail me at tdo1@psu.edu and I will send you another survey. If you have ***not*** participated in building material or selection or purchase within the last five years, please let me know the name of an appropriate person in your organization to whom I should address any future correspondence.

Thank you for your help!

Sincerely,

Tracy Davis O'Connell

Tracy Davis O'Connell
Penn State University, Research Assistant

Appendix 19: Distributor Letter

PENNSTATE

(814) 863-3450
FAX: (814) 863-7193

School of Forest Resources
College of Agricultural Sciences

The Pennsylvania State University
305 Forest Resources Laboratory
University Park, PA 16802

9 November 2002

«fullname», «title»
«company»
«mail_address»
«mail_city», «mail_state» «mail_zip»

Dear «fullname»:

We are conducting a survey to investigate durability and performance perceptions of current and potential new building materials. It is important to solicit opinions from key wholesalers to better understand factors affecting your selection and purchase of various building materials. We have contacted you because your company is a leader in the building materials industry.

This voluntary survey is designed for easy completion and will take approximately 10 to 15 minutes of your time. We recognize your time is valuable and have therefore made every attempt to make this easy to fill out and return. After you finish the survey, please tape it closed and place it in the mail. We pay the postage. (If you have ***not*** participated in building material or selection or purchase within the last five years, please forward this to an appropriate person in your organization.)

This survey if **anonymous and completely confidential** and only summary information will be reported in the study results. The number inside this survey is an **identifier only** that allows us to track when we receive your completed survey ensuring that you do not receive subsequent surveys or phone calls.

The information we collect will help those developing new technologies/materials/products to better understand your building material perceptions and product selection/adoption concerns. We would be pleased to provide you with a **complimentary summary of the study results** as a token of appreciation for completing the survey. Just attach a business card or write your firm's name and mailing address inside the back cover of your completed survey. Or if you wish, you may request a summary of the results by sending a separate written request or by email.

As an additional token of our appreciation for completing the survey, we would like to enter your name in a drawing for a comfortable Penn State sweatshirt with an embroidered PSU logo. (I know this is a bit of a gimmick, but we really do need your help!) If you have any questions

about this research study, please call (814) 865-8841 or e-mail me at tdo1@psu.edu. Your help is essential to the study's success.

Thank you for your time and thoughtful input.

Sincerely,

Tracy Davis O'Connell
Penn State University, Research Assistant

Appendix 20: Distributor Follow-Up Letter

PENNSTATE

(814) 863-3450
FAX: (814) 863-7193

1855

School of Forest Resources
College of Agricultural Sciences

The Pennsylvania State University
305 Forest Resources Laboratory
University Park, PA 16802

2 December 2002

«fullname», «title»
«company»
«mail_address»
«mail_city», «mail_state» «mail_zip»

Dear «fullname»:

About three weeks ago a questionnaire regarding durability and performance perceptions of current and potential new building materials was mailed to you. Even if you feel that your contribution to this study is minor, it is important that we receive your input. The information that we collect will help those developing new materials to better understand factors affecting your selection and purchase of various building materials.

If you have already completed the questionnaire and returned it, please accept our sincere thanks! If not, we urge you to do so today. In case our other correspondence did not reach the person at your firm whose response is needed, a replacement questionnaire is enclosed. Please remember that the survey is anonymous and completely confidential and only summary information will be reported in the study results.

We would be pleased to provide you with a summary of the study results. Just attach a business card or write your firm's name and mailing address inside the back cover of your completed survey. And there is still time to be entered into the drawing for the comfortable embroidered Penn State sweatshirts!

Your contribution to the success of this study will be greatly appreciated. If you have any questions about the research study, please call (814) 865-8841 or e-mail me at tdo1@psu.edu.

Thank you for your time and thoughtful input.

Sincerely,

Tracy Davis O'Connell
Research Assistant

Appendix 21: Distributor Post Card

PENNSTATE

(814) 863-3450
FAX: (814) 863-7193

School of Forest Resources
College of Agricultural Sciences

The Pennsylvania State University
305 Forest Resources Laboratory
University Park, PA 16802

18 November 2002

Dear Distributor:

Last week a questionnaire regarding durability and performance perceptions of current and potential new building materials was mailed to you. Even if you feel that your contribution to this study is small, it is important that we receive your input. Only a limited number of firms are receiving this survey. Your opinions are needed to help guide product and market development decisions. The information we collect will help those developing new building materials to better understand your concerns for new and replacement products.

If you have already completed the questionnaire and returned it, please accept our sincere thanks! If not, we encourage you to do so today. Please remember that the survey is anonymous and completely confidential and only summary information will be reported in the study results. We will be pleased to provide you with a complimentary summary of the study results upon request. Just attach a business card or write your firm's name and mailing address inside the back cover of your completed survey. And we would also like to enter you name in the drawing for the Penn State sweatshirts!

If you did not receive the questionnaire or misplaced it, please call me at (814) 865-8841 or e-mail me at tdo1@psu.edu and I will send you another survey. If you have ***not*** participated in building material or selection or purchase within the last five years, please let me know the name of an appropriate person in your organization to whom I should address any future correspondence.

Thank you for your help!

Sincerely,

Tracy Davis O'Connell

Tracy Davis O'Connell
Penn State University, Research Assistant

Appendix 22: Retailer Letter

PENNSTATE

(814) 863-3450
FAX: (814) 863-7193

School of Forest Resources
College of Agricultural Sciences

The Pennsylvania State University
305 Forest Resources Laboratory
University Park, PA 16802

9 November 2002

«fullname», «title»
«company»
«mail_address»
«mail_city», «mail_state» «mail_zip»

Dear «salutation». «last_name»:

We are conducting a survey to investigate durability and performance perceptions of current and potential new building materials. It is important to solicit opinions from key retailers to better understand factors affecting your selection and purchase of various building materials. We have contacted you because your company is a leader in the building materials industry.

This voluntary survey is designed for easy completion and will take approximately 10 to 15 minutes of your time. We recognize your time is valuable and have therefore made every attempt to make this easy to fill out and return. After you finish the survey, please tape it closed and place it in the mail. We pay the postage. (If you have ***not*** participated in building material or selection or purchase within the last five years, please forward this to an appropriate person in your organization.)

This survey if **anonymous and completely confidential** and only summary information will be reported in the study results. The number inside this survey is an **identifier only** that allows us to track when we receive your completed survey ensuring that you do not receive subsequent surveys or phone calls.

The information we collect will help those developing new technologies/materials/products to better understand your building material perceptions and product selection/adoption concerns. We would be pleased to provide you with a **complimentary summary of the study results** as a token of appreciation for completing the survey. Just attach a business card or write your firm's name and mailing address inside the back cover of your completed survey. Or if you wish, you may request a summary of the results by sending a separate written request or by email.

As an additional token of our appreciation for completing the survey, we would like to enter your name in a drawing for a comfortable Penn State sweatshirt with an embroidered PSU logo. (I know this is a bit of a gimmick, but we really do need your help!) If you have any questions

about this research study, please call (814) 865-8841 or e-mail me at tdo1@psu.edu. Your help is essential to the study’s success.

Thank you for your time and thoughtful input.

Sincerely,

Tracy Davis O’Connell
Penn State University, Research Assistant

Appendix 23: Retailer Follow-Up Letter

PENNSTATE

(814) 863-3450
FAX: (814) 863-7193

School of Forest Resources
College of Agricultural Sciences

The Pennsylvania State University
305 Forest Resources Laboratory
University Park, PA 16802

2 December 2002

«fullname», «title»
«company»
«mail_address»
«mail_city», «mail_state» «mail_zip»

Dear «salutation». «last_name»:

About three weeks ago a questionnaire regarding durability and performance perceptions of current and potential new building materials was mailed to you. Even if you feel that your contribution to this study is minor, it is important that we receive your input. The information that we collect will help those developing new materials to better understand factors affecting your selection and purchase of various building materials.

If you have already completed the questionnaire and returned it, please accept our sincere thanks! If not, we urge you to do so today. In case our other correspondence did not reach the person at your firm whose response is needed, a replacement questionnaire is enclosed. Please remember that the survey is anonymous and completely confidential and only summary information will be reported in the study results.

We would be pleased to provide you with a summary of the study results. Just attach a business card or write your firm's name and mailing address inside the back cover of your completed survey. And there is still time to be entered into the drawing for the comfortable embroidered Penn State sweatshirts!

Your contribution to the success of this study will be greatly appreciated. If you have any questions about the research study, please call (814) 865-8841 or e-mail me at tdo1@psu.edu.

Thank you for your time and thoughtful input.

Sincerely,

Tracy Davis O'Connell
Research Assistant

Appendix 24: Retailer Post Card

PENNSTATE

(814) 863-3450
FAX: (814) 863-7193

School of Forest Resources
College of Agricultural Sciences

The Pennsylvania State University
305 Forest Resources Laboratory
University Park, PA 16802

18 November 2002

Dear Retailer:

Last week a questionnaire regarding durability and performance perceptions of current and potential new building materials was mailed to you. Even if you feel that your contribution to this study is small, it is important that we receive your input. Only a limited number of firms are receiving this survey. Your opinions are needed to help guide product and market development decisions. The information we collect will help those developing new building materials to better understand your concerns for new and replacement products.

If you have already completed the questionnaire and returned it, please accept our sincere thanks! If not, we encourage you to do so today. Please remember that the survey is anonymous and completely confidential and only summary information will be reported in the study results. We will be pleased to provide you with a complimentary summary of the study results upon request. Just attach a business card or write your firm's name and mailing address inside the back cover of your completed survey. And we would also like to enter you name in the drawing for the Penn State sweatshirts!

If you did not receive the questionnaire or misplaced it, please call me at (814) 865-8841 or e-mail me at tdo1@psu.edu and I will send you another survey. If you have ***not*** participated in building material or selection or purchase within the last five years, please let me know the name of an appropriate person in your organization to whom I should address any future correspondence.

Thank you for your help!

Sincerely,

Tracy Davis O'Connell

Tracy Davis O'Connell
Penn State University, Research Assistant

Durable Wood Composites For Naval Low-Rise Buildings

Value Propositions for OSB (Oriented Strand Board)

Siding and Trim Components

Task S2 - Examine the value propositions for specific residential siding and siding accessories and OSB products from the perspective of the manufacturer and key channel members.

Paul Smith *Pennsylvania State University*
Sudipta Damohapatra *Pennsylvania State University*

Prepared for
Office of Naval Research
under Grant N00014-03-1-0949

Project End Report
January 2007

Pennsylvania State University
210 Forest Resources Building
University Park, PA 16802
Tel: 814-854-8841
Fax: 814-863-7193

ABSTRACT

The OSB industry was studied under task S2 to better understand value propositions for manufactures and their key wholesale distributors. The complete report was included in the March 2006 Progress Report prepared for the ONR under this Grant (N00014-03-1-0949).

This study[1] examines the attributes of OSB sheathing that are important to North American OSB wholesale buyers when making their purchase decisions. The gap/match in the perceived importance of various OSB sheathing attributes among OSB supplier firms and OSB wholesale buyer firms was examined. Data for this cross-sectional study was collected in Fall 2003 and Spring 2004 from a sample of building material wholesale buyers and OSB supplier firms. A 22.3 percent response rate (n=72, representing 3.56 billion square feet, 3/8 inch basis, of OSB sheathing purchased in 2002) was obtained from 323 OSB wholesale sheathing buyers and a 78 percent response rate (n= 14, accounting for 18.4 billion square feet, 3/8 inch basis, of OSB produced in 2002) was obtained from 18 OSB supplier firms in North America.

According to the study's 72 OSB wholesale respondents, absence of delamination and thickness uniformity are perceived to be the most important product attributes in floor sheathing, whereas competitive price is perceived as the most important product attribute in roof/wall sheathing. Timely delivery is the most important service attribute for wholesale buyers in roof, wall, and floor sheathing products.

A comparison between OSB wholesaler and their supplier's rating of importance of sheathing attributes showed significant ($p<0.05$) negative gaps (buyer importance rating > supplier importance rating) in perceptions of thickness uniformity (roof and wall sheathing), presence of edge sealing (floor sheathing), availability of environmentally certified products (roof, wall, and floor sheathing), and buyer-supplier relationship (roof, wall, and floor sheathing). Significant positive gaps (buyer importance rating < supplier importance rating) in perceptions were found for dimensional stability (roof and wall sheathing), brand (floor sheathing), and use of ecommerce technology (roof, wall, and floor sheathing).

Understanding the mismatch (or gap) between a firm's perceptions and its customer's view provides valuable information to the OSB manufacturing firms to correct these gaps by appropriately allocating its capital and personnel for a greater profitability and superior competitive advantage.

[1] *This work was co-authored by Sudipta Dasmohapatra and Paul M. Smith and published in the Proceedings of 39th International Wood Composites Symposium and Technical Workshop, Pullman, Washington, April 4-7, 2005. Pp. 47-55. A reprint of this article may be found in the Appendix.*

Perceptions of Sheathing Attributes by OSB Wholesalers and Manufacturers

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Abstract

This study examines the attributes of oriented strandboard (OSB) sheathing that are important to North American OSB wholesale buyers when making their purchase decisions. Gap/match in the perceived importance of various OSB sheathing attributes among OSB supplier firms and OSB wholesale buyer firms was examined. Data for this cross-sectional study was collected in Fall 2003 and Spring 2004 from a sample of building material wholesale buyers and OSB supplier firms. A 22.3 percent response rate ($n = 72$, representing 3.56 billion ft.^{2}, 3/8-in. basis, of OSB sheathing purchased in 2002) was obtained from 323 OSB wholesale sheathing buyers and a 78 percent response rate ($n = 14$, accounting for 18.4 billion ft.^{2}, 3/8-in. basis, of OSB produced in 2002) was obtained from 18 OSB supplier firms in North America.

Results of the study indicate that OSB wholesale respondents perceived floor sheathing attributes differently from roof and wall sheathing attributes. According to the study's wholesale respondents, absence of delamination and thickness uniformity are perceived to be the most important product attributes in floor sheathing, whereas competitive price is perceived as the most important product attribute in roof/wall sheathing. Timely delivery is the most important service attribute for wholesale buyers in roof, wall, and floor sheathing products. A comparison between OSB wholesalers and their supplier's rating of importance of sheathing attributes showed signifi-

cant ($p < 0.05$) negative gaps (buyer importance rating > supplier importance rating) in perceptions of thickness uniformity (roof and wall sheathing), presence of edge sealing (floor sheathing), availability of environmentally certified products (roof, wall, and floor sheathing), and buyer-supplier relationship (roof, wall, and floor sheathing). Significant positive gaps (buyer importance rating < supplier importance rating) in perceptions were found for dimensional stability (roof and wall sheathing), brand (floor sheathing), and use of ecommerce technology (roof, wall, and floor). Understanding the mismatch between a firm's perceptions and its customer's view provides valuable information to the OSB manufacturing firms to correct these gaps by appropriately allocating its capital and personnel for a greater profitability and superior competitive advantage.

Introduction

Since its introduction in the North American structural panel market in the early 1980s, the oriented strandboard (OSB) industry has grown to enormous proportions. Competing with its structural panel counterpart, plywood, OSB is now the dominant panel product of choice, especially in the residential construction market. As an engineered structural panel, OSB has been dominating the residential construction market, which accounts for approximately 65 percent of all OSB used in North America in 2003 (**Fig. 1**). The second largest OSB construction market is the repair and remodeling (R&R) market which consumed 25 percent of the OSB produced in 2003, followed by the non-residential market (6%), industrial (3%), and export market (1%).

In 2002 and 2003, there were 18 OSB manufacturers in North America operating 63 mills (Adair 2004). These few suppliers compete primarily on price for market share gains (Damery 2003). Recently, however, because of fluctuations in prices, capacity increases, and an increase in substitute products, the OSB competitive environment is facing many changes. Until 2002, OSB prices had typically shown a decreasing trend, thereafter the prices increased astronomically. A strong housing demand, reduced inventories with building material distributors, and a delay in logging season are some of the key reasons for this price increase. Additionally, increasing OSB mill capacity (25% in 1996, 5% in 1997 and 1998, 3% in 1999, and 5% in 2003 and 2004) is likely to have a huge impact on the entire market driving down prices, thus creating a slowdown in production and demand. These factors, combined with growing OSB sheathing product substitutes and imports (e.g., plywood from Brazil and Chile and OSB from Europe) make it important for OSB supplier firms to reexamine the key premises of their product offerings and deliver superior products to meet changing customer needs and demands (Bumgardner and Schular 2002). This research study examines the key decision factors used by OSB wholesale buyers to make their OSB purchase decisions in the changing marketplace. A better understanding of these variables will provide pertinent information to competing manufacturers on product development/differentiation opportunities and allow firms to develop strategic tools for sustained competitive advantage.

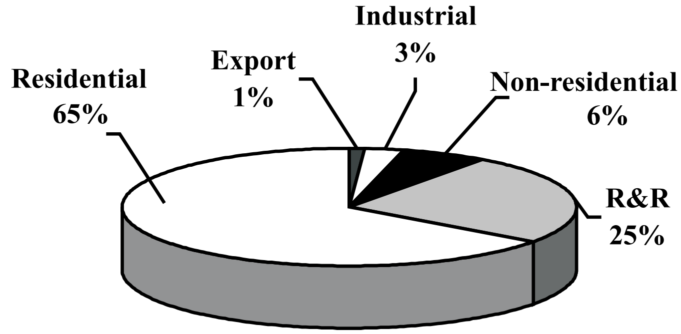

Figure 1.—OSB end uses in North America in 2003. Source: Adair (2004).

A review of relevant marketing literature showed a surprising dearth of published information pertaining to the OSB industry. Prior research has concentrated primarily on understanding brand perceptions of the OSB manufacturers and retailers (Seward and Sinclair 1988a, 1988b; Sinclair and Seward 1988) and understanding the product diffusion process (Shook et al. 1998). This paper updates and adds to the previous research by providing more information on the current customer perceptions in the OSB industry in its sheathing product segment, which is the single

largest application of the product in the residential construction industry. Additionally, this paper investigates gaps and/or matches in the perceptions of selected OSB sheathing attributes among OSB buyers and their suppliers. It is important to understand any mismatch in perceptions between suppliers and customers because if the attribute perceptions of the producer and customer do not coincide, then producers may be emphasizing the wrong attributes in their communication programs and losing customers (Day 1990).

Gap/Match in Attribute Perceptions Between Supplier and Buyer

Past surveys and studies have found major misalignments among perceptions of supplier firms' and their customers' expectations about the marketplace offerings (Smith 2002, Ulaga and Chacour 2001, Winfurter and Hansen 1999, Band 1995, Naumann 1995, Idassi et al. 1994). Results of a cross-national study by Ulaga and Chacour (2001) on food manufactures and buyers showed that while suppliers perceive price to be as important as product and service quality attributes, customers were less price sensitive and weighted quality attributes much higher than price. Winfurter and Hansen (1999) indicate that suppliers in the softwood lumber market constantly overrate their performance level relative to how they are rated by their customers; this mismatch in perceptions leads to an inappropriate allocation of resources by the supplier firms. Past studies on understanding perceptions of structural panel retailers and their manufacturers also suggests gaps in perceptions of brand selection attributes among the two groups (Seward and Sinclair 1988a). The aforementioned study found that while OSB retailers indicated price to be the most important attribute for brand selection, manufacturers rated high quality/performance as the most important brand selection criteria.

The key reason for the perception gap between buyers and suppliers is suggested as unintentional organizational barriers that keep supplier firms from shifting from an internal company focus to one that encourages superior customer value delivery (Gale 1994, Band 1991). Defining the worth of a product internal to the company will be of little importance because a product is perceived as high value only if it meets the customer needs and requirements. Matching a firm's perception of a product with that of their customers can help the supplier firms' to use their resources and capabilities to deliver a better product in order to gain the most promising competitive advantage (Winfurter and Hansen 1999).

Research Objectives

The overall objective of this study is to investigate the relative importance of selected OSB sheathing attributes in the OSB wholesaler customer's purchase decisions. The second objective is to compare the OSB wholesaler perceptions of these sheathing attributes with that of their OSB suppliers in order to identify perceived gaps and/or matches.

Research Methodology

Sampling

The database used to generate the sample of building material wholesalers in North America was sourced from the latest CD-ROM Directory of Building Products and Hardlines Distributors of the trade magazine: *Chain Store Guide (CSG)*. Published since 1925, this trade magazine is a leading source of information for various market segments, including wholesale building material industry. The sample of the building material wholesalers in North America surveyed included the top 200 building material wholesalers from the database (representing 42%, i.e., $23.3 billion of a roughly $55 billion industry) and included the major and perhaps the most influential companies in the buyer segment (Chain Store Guide 1999). In addition, a systematic random sample of 800 building material wholesalers was then selected from the remaining building material wholesale distributor list (1,223 wholesale firms) to ensure appropriate representation of large, medium, and small OSB wholesale buyers. The sample size used in this research was considered appropriate for statistical analysis based on a 95 percent confidence interval, assuming population size for normal distribution (Krueger 2001).

A list of OSB manufacturers operating in North America in 2002/2003 (n = 18) was available from APA–The Engineered Wood Association and used in this study.

Given the availability of various databases, the aforementioned databases were chosen based on their size, stratification quality, availability, and cost.

Data Collection Procedure

A modified version of Dillman's (2000) tailored design method was used for data collection from OSB manufacturers and building material wholesaler sample. Survey questionnaires were mailed to the 1,000 building material wholesale customer firms included in our sample in Fall of 2003 and to all 18 OSB manufacturing firms in Spring of 2004. A reminder postcard was sent to all contacts approximately one week after the first mailing. This was followed two weeks later by a second mailing with a cover letter requesting participation from the non-respondents. Because of low response rates from wholesale building material buyers after the second mailing, another reminder letter and a follow-up third mailing was sent to non-respondents. Follow-up phone calls and emails were conducted following the third mailing to generate additional responses.

Response Rate

After the follow-up mailings and phone calls, an overall response rate of 78 percent was received (n = 14, representing 81% or 18.4 billion ft.^{2} of the total OSB produced in 2002) from all 18 North American OSB suppliers (**Table 1**).

The OSB wholesale sample frame was dramatically reduced from n = 1,000 to n = 432 due primarily to the fact that most building material wholesalers indicated they did not purchase OSB sheathing products. Wholesalers who did not purchase OSB sheathing in 2002 (e.g., building material hardware firms, industrial distributors, office wholesalers, n = 568) were removed from our population. After accounting for non-deliverable questionnaires and firms who refused to participate (n = 109), an adjusted response rate of 22.3 percent (n = 72) for 323 wholesalers was obtained (**Table 1**). Our respondent wholesale firms (n = 72) represent over 3.56 billion ft.^{2} of OSB sheathing in 2002 or 28 percent of the 12.9 billion ft.^{2} of OSB sold via the wholesale channel. Among these respondents, the top 200 respondent wholesalers (n = 28) accounted for 2.947 billion ft.^{2} (3/8-in. basis) of OSB in 2002 and the smaller respondents from the random sample (n = 44) represented 627 million ft.^{2} (MMSF) (3/8-in. basis).

Nonresponse Bias

To assess potential nonresponse bias, building material wholesale customers who responded to the initial survey mailing (early respondents, n = 34) were compared to those who responded after follow-up steps were taken (late respondents, n = 38) using ANOVA[1]. The later respondents are generally believed to behave more like nonrespondents (Pearl and Fairly 1985). The variables used for this comparison are volume of OSB purchased in 2002, customer types, and attribute importance ratings. No significant differences (at the 0.05 level) are found between

[1] Anaylsis of variation (ANOVA) procedure is a test of difference that determines if the mean values of an independent variable are significantly different from each other within each category of an independent variable (SPSS 1999).

Table 1.—Response rate from OSB wholesale and supplier firms.

	Initial sample	Non-usable, responses[a]	Adjusted population	Adjusted response rate	OSB purchased/produced (3/8-in. basis, 2002)
Building material wholesalers	1,000	677	323	22.3% (n = 72)	3.56 billion ft.^{2b}
OSB manufacturing firms	18	--	18	78% (n = 14)	18.4 billion ft.^{2c}

[a] Included undeliverables, building material hardware firms, and industrial distributors who did not purchase OSB sheathing.
[b] 28% of the 12.9 billion ft.^{2} of OSB sold via the wholesale channel.
[c] 81% of total OSB produced in North America in 2002 (22.7 billion ft.^{2}, 3/8-in. basis).

the two groups (early and late respondents) on their mean overall volume of OSB purchased in 2002 and perceptions of attribute importance. However, late respondents sold significantly more (42%) OSB sheathing to residential builders as compared to that of early respondents (24%) and significantly less (3%) OSB sheathing to industrial customers than that of the early respondents (19%) (at 0.05 significance level).

Results

Respondent Profile

Respondent OSB manufacturer firms were asked to indicate their customer type by percent of OSB volume in 2002. Responding firms ($n = 14$ representing 81% of the North American OSB production in 2002) sold 57 percent of their OSB directly to their wholesalers (independent wholesalers 22%; buying co-ops 15%; office wholesalers 12%; captive wholesalers 8%), followed by retailers (31%), industrial customers (6%), residential builders (3%), mobile home manufacturers (1%), and others (2%) in 2002 (**Table 2**).

Table 2 also shows that retailers were the most important customer type for the study's 72 OSB wholesale respondents representing 46 percent of their entire OSB sales in 2002, followed by builders (38%), industrial customers (10%), do it yourself (DIY) customers (3%), mobile home manufacturers (2%), and office contractors (1%).

Table 2.—Percent of OSB purchase (by volume) by customer type in 2002.

Customer type	Mean percent: OSB manufacturing firms $n = 14$[a]	Mean percent: OSB wholesaler firms $n = 72$[b]
	- - - - - - - (%) - - - - - - -	
Retailers	31	46
Independent wholesalers	22	--
Buying co-ops	15	--
Office wholesalers	12	1
Captive wholesalers	8	--
Industiral customers	6	10
Residential builders	3	32
Mobile home manufacturers	1	2
Non-residential builders	0	6
DIY's	--	3
Others	2	--
Total	100	100

[a] Represents 81% of OSB produced in 2002.
[b] Represents 28% of all OSB produced in 2002.

The mean volume of OSB purchased by our OSB wholesale respondents ($n = 72$) in 2002 was 49.6 MMSF, 3/8-inch basis. Over 26 percent of respondents indicated less than 1 MMSF (3/8-in. basis) of OSB sheathing purchased in 2002 whereas 14 percent purchased more than 50 mmsf (**Fig. 2**).

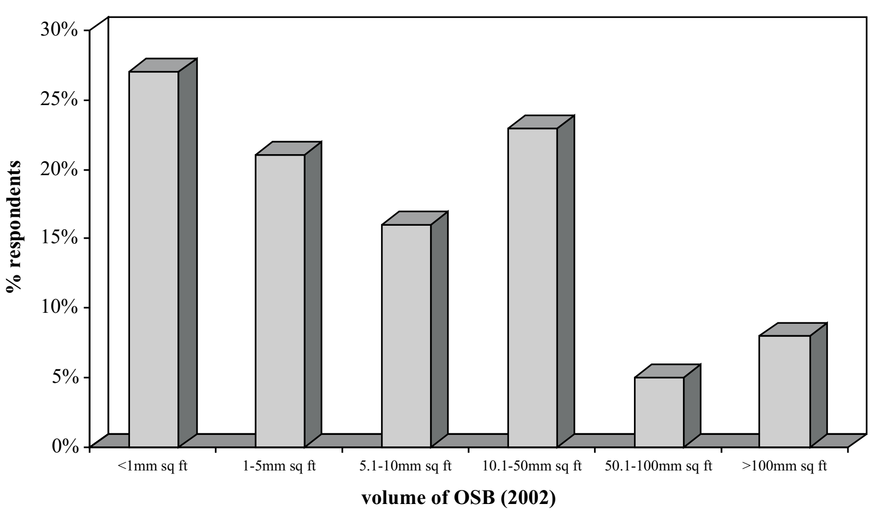

Figure 2.—Wholesaler volume of OSB sheathing purchased in 2002 ($n = 72$). Total volume = $3.26 million (3/8-in. basis) representing 28% of OSB sold via wholesale channel.

Perceived Importance Ratings of OSB Product/Service Attributes

OSB wholesaler and supplier study respondents were asked to rate the relative importance of attributes for both roof/wall and floor sheathing as they relate to their OSB structural sheathing purchase or sale (on a six-point rating scale of importance, 0 = no importance and 5 = extremely important). A list of pertinent OSB sheathing product and service quality attributes used in this study were identified using a variety of sources (APA 2000; SBA 1998–2002; Shook et al. 1998; Seward and Sinclair 1988a, 1988b; Seward 1986; OSB supplier and buyer websites). OSB industry specialists[2] from the study's expert panel indicated that OSB product attributes were similar for roof and wall sheathing products; however, floor sheathing products possessed a different array of product attributes. As a result, product attribute importance was measured separately for roof/wall sheathing and floor sheathing.

Overall, product attributes for floor sheathing products were perceived as more important than corresponding product attributes for roof/wall sheathing products by both OSB wholesalers and their supplier firms (**Table 3**). Results show that for floor sheathing, OSB wholesalers rated absence of delamination (mean rating = 4.6) and thickness uniformity (mean rating = 4.6) as the two most important floor sheathing attributes (**Table 3**). However, in the roof/wall sheathing segment, the wholesale customers rated competitive price (mean rating = 4.6) and absence of delamination (mean rating = 4.5) as the two most important attributes. Availability of environmentally certified product received the lowest importance rating from the responding wholesale buyers for OSB roof/wall as well as floor sheathing products (**Table 3**).

On-time delivery was rated as the most important service attribute (mean rating = 4.6) followed by product availability (mean rating = 4.2) (**Table 4**). Availability of e-commerce technology received the

[2] Includes OSB researcher Craig Adair, APA-The Engineered Wood Association; Panel Manager Jim McGovern, LP Corporation; and Panel Trader Vern Dando, LMC.

Table 3.—OSB product attribute importance by OSB wholesale distributor and suppliers.

	Floor sheathing			Roof/wall sheathing		
	Mean importance scores[a]			Mean importance scores[a]		
Product attributes	Wholesalers $n = 61$	Suppliers $n = 11$	Signifiance[b] p value	Wholesalers $n = 68$	Suppliers $n = 14$	Signifiance[b] p value
Absence of delamination	4.6	4.8	0.786	4.5	4.6	0.832
Thickness uniformity	4.6	4.7	0.916	**4.2**	**3.7**	**0.042**[c]
Dimensional stability	4.5	4.9	0.362	**3.8**	**4.3**	**0.049**[d]
Competitive price	4.5	4.4	0.874	4.6	4.7	0.852
Edge sealing	**4.1**	**3.3**	**0.39**[c]	3.7	3.6	0.780
Price flexibility	3.9	4.0	0.921	3.9	3.7	0.563
Impact resistance	3.7	3.9	0.748	3.3	3.1	0.461
Surface smoothness	3.7	3.6	0.802	3.0	2.5	0.064
Brand	**3.2**	**4.3**	**0.027**[d]	2.3	2.7	0.121
Availability of environmentally certified product	**2.5**	**1.3**	**0.009**[c]	**2.1**	**1.5**	**0.013**[c]

[a] Mean importance scores on product attributes measured on a six-point importance score of 0 = no importance to 5 = extremely important.
[b] Values in bold represent significant differences between groups using Mann-Whitney test at 0.05 level of significance.
[c] Negative perception gap (mean wholesaler rating > mean supplier rating).
[d] Positive perception gap (mean wholesaler rating < mean supplier rating).

lowest importance rating from OSB wholesale buyers (mean rating = 2.0) among service attributes.

It is important to note that geographic closeness to a supplier was considered to be highly important in purchase decisions during preliminary discussions with OSB researchers and managers of OSB supplier firms (personal communication with OSB supplier firms and association experts); however, results indicate that this variable is perceived as the seventh most important attribute by OSB wholesale buyers (**Table 4**).

Compared to the OSB wholesale buyers who rated absence of delamination and thickness uniformity as their most important floor sheathing attributes, OSB suppliers rated dimensional stability as the most important attribute in floor sheathing (mean rating = 4.9) (**Table 3**). In the roof and wall sheathing segments however, OSB suppliers rated competitive price (mean rating = 4.7) and absence of delamination (mean rating = 4.6) as the two most important attributes similar to the OSB wholesaler's perceptions. Additionally, timely delivery was rated as the most important service attribute (mean rating = 4.7) by the OSB suppliers (**Table 4**).

Match/Gap in Perceived Importance Ratings of OSB Sheathing Attributes

Tests for significant differences (ANOVA and Mann-Whitney U test) were conducted to compare and identify gaps and matches in the importance rating perceptions of OSB wholesaler and supplier firms on corresponding product and service attributes. Any significant gap between the supplier and wholesaler rating can negatively affect the product and service quality of an offering and ultimately a firm's profitability (Idassi et al. 1994).

As represented in **Table 3**, among floor sheathing product attributes, significant perception gap ($p < 0.05$) exists for "edge sealing", "brand", and "availability of environmentally certified product". Additionally, among roof and wall sheathing product attributes significant perception gap ($p < 0.05$) exists for "thickness uniformity", "dimensional stability", and "availability of environmentally certified product"

Table 4.—OSB service attribute importance by OSB wholesale distributors and suppliers (all sheathing types).

Service attributes	Mean importance scores[a] Wholesalers $n = 69$	Suppliers $n = 14$	Significance[b] p value
On-time delivery	4.6	4.7	0.776
Product availability	4.2	4.2	0.908
Personal relationship with supplier/customer	**4.0**	**3.3**	**0.048**[c]
Company reputation	3.7	3.9	0.558
Good credit terms	3.7	3.4	0.251
Availability of a range of sizes	3.5	3.2	0.328
Geographic closeness	3.4	3.4	0.876
Strong technical support	3.1	2.9	0.493
Full product line	3.4	3.7	0.503
Packaging	3.0	2.4	0.076
Strong promotional support	2.4	2.6	0.399
Use of e-commerce technology	**2.0**	**2.7**	**0.018**[d]

[a] Mean importance scores on product attributes measured on a six-point importance score of 0 = no importance to 5 = extremely important.
[b] Figures in bold represent significant differences between groups using Mann-Whitney test of significance at 0.05 level of significance.
[c] Negative perception gap (mean wholesaler rating > mean supplier rating).
[d] Positive perception gap (mean wholesaler rating < mean supplier rating).

(**Table 3**). Among OSB service attributes, significant gaps at the 0.05 level between respondent supplier and wholesaler firm's perceptions exist for "personal relationship between buyer and supplier" and "use of e-commerce technology" (**Table 4**).

The aforementioned gaps in perceptions could be categorized as positive or negative. A negative gap occurs when the customer's mean response to an attribute is greater than the supplier's mean response for the corresponding attribute and vice versa (Idassi et al. 1994). Among OSB product attributes, significant negative gap (mean supplier ratings < mean customer ratings) in perceptions between supplier and wholesaler firms exist for thickness uniformity and availability of environmentally certified product in roof/wall sheathing and edge sealing and availability of environmentally certified product in floor sheathing (**Table 3**). As represented in **Table 3**, significant positive gaps (mean supplier ratings > mean customer ratings) among product attributes exist for dimensional stability in roof and wall sheathing and brand in floor sheathing. Among service attributes, a significant negative gap occurs for personal relationship between buyer and supplier and a positive gap exists for the use of e-commerce technology perceptions (**Table 4**).

Researchers indicate that while knowledge of both types of gaps (negative and positive) is of critical value to the supplier, negative gaps are considered more important because identifying these gaps may be critical for a company to maintain its present level of customers and to design proactive strategies for improving customer relations (Idassi et al. 1994, Band 1990). Positive perception gaps may not be necessarily good either because they can indicate an over commitment of resources in one or more areas that may not be critically important to the customer. Correcting these perception gaps may help OSB supplier firms to improve their offerings and better meet their wholesale customer needs.

Conclusion

This paper provides an examination of the perceived importance of product and service attributes within two product segments in the OSB sheathing industry. Findings from our study show that the floor sheathing product attributes were rated higher in terms of their importance as compared to the ratings of corresponding attributes for roof and wall sheathing products by OSB wholesalers as well as suppliers. Among product attributes, absence of delamination and thickness uniformity in the floor sheathing products and competitive price in the roof/wall sheathing products received the highest importance rating. Among service attributes, on-time delivery was the most important attribute indicated by OSB wholesale buyers and suppliers.

This study uses gap analysis to identify inconsistencies between supplier and customer perceptions of product and service importance. The results suggest that significant negative gaps exist among OSB wholesale buyers and their supplier's importance perception of edge sealing in floor sheathing, thickness uniformity in roof/wall sheathing, availability of environmentally certified product (roof/wall and floor sheathing), and personal relationship between buyer and supplier in all three sheathing types. If suppliers concentrate their efforts and design appropriate strategies focused on these negative perception gaps, they might prevent loss of customers to their competitors. In addition, significant positive gaps ($p < 0.10$) were seen among OSB wholesale buyers and OSB supplier's ratings of the importance of dimensional stability (roof/wall sheathing), brand (floor sheathing), and use of e-commerce technologies (roof/wall/floor sheathing). These areas may be of primary concern to OSB suppliers for any over allocation of resources and consequent loss of revenue.

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Durable Wood Composites For Naval Low-Rise Buildings

Value Propositions for Specific Residential Siding and Siding Accessories

Siding and Trim Components

Task S2 - Examine the value propositions for specific residential siding and siding accessories and OSB products from the perspective of the manufacturer and key channel members.

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SUMMARY

Value Propositions for Residential Siding

Residential Siding – Builder perspective:

***Discriminant maps* -** A factor analysis using performance ratings was conducted to identify the structure in the relationship between the 16 attributes important in siding purchase decisions of builders. The Principal Component method and varimax rotation was used to extract orthogonal factors (with Eigen value greater than 1). Four factors were extracted that explain 67% of the variance among the attribute ratings. Table 1 shows factor scores by the 4 factors.

Table 1. Factor Scores by Attribute Performance

Rotated Component Matrix

	Component			
	1	**2**	**3**	**4**
Durability	0.845			
Reduce complaint	0.838			
Status/Image	0.663			
Curb Appeal	0.660			
Manufacturers guarantee	0.602			
Damage Resistance	0.558			
Installation Costs		0.816		
Easier Installation		0.792		
Purchase Price		0.731		
Customer demand		0.503		
Variety of Styles		0.471		
Availability			0.860	
Ontime delivery			0.810	
Sales rep contact				0.805
Low Maintenance				0.572
Dealer terms				0.506

Extraction Method: Principal Component Analysis. Rotation Method: Varimax v

a Rotation converged in 9 iterations.

Table 2. Factor Labels and Attributes

	Factor1	Factor2	Factor3	Factor4
	Durability/ Damage Resistance	**Cost/Price**	**Availability**	**Dealer terms/ Sales Rep Service**
Attributes	Durability Reduce Complaint Status/Image Curb Appeal Manufacturers Guarante Damage Resistance	Installation Costs Easier Installation Purchase Price Customer Demand Variety of Styles	Ontime Delivery	Low Maintenance Dealer Terms

Solid wood falls out of the range of the map and is really low on all the above factors. Based on builder ratings and practical considerations we can only compare aluminum/steel, vinyl and composites (includes, hardboard, OSB, fiber-cement and WPC) shown in the map.

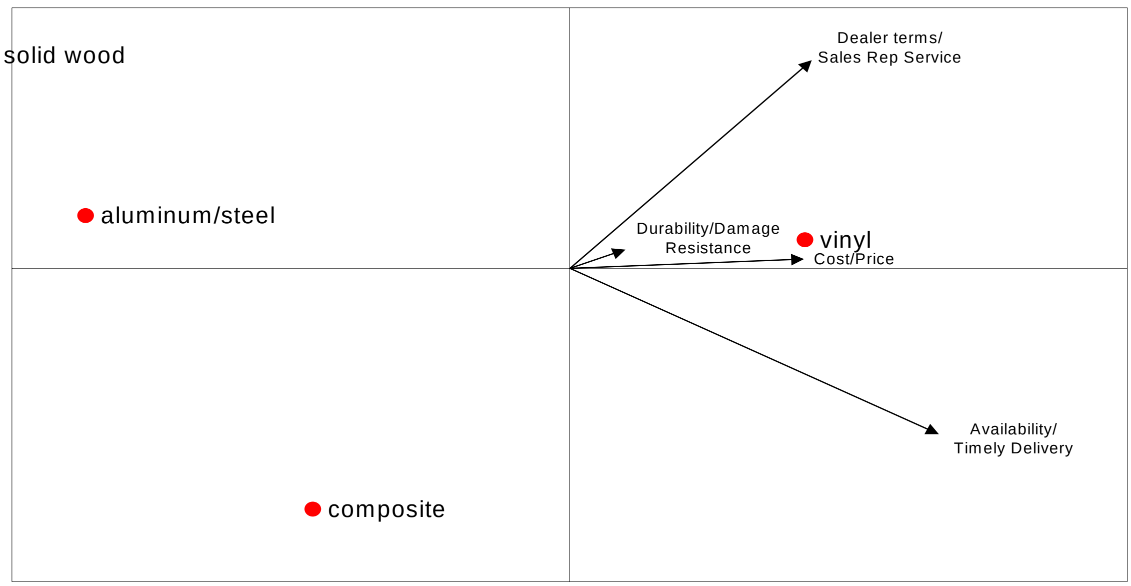

Figure 1. Discriminant Map of Siding Materials by Factors

The following pointers will assist with interpreting the discriminant maps shown above and how the siding material segments differ on key dimensions (factors): (1) The arrows on the maps represent those factors that significantly discriminate between the segments; (2) The relative length of each arrow on the maps represent the relative discriminating power of each factor; and (3) Segments furthest in the direction of an arrow are rated highest on the factor and segments furthest in the opposite direction of an arrow is rated lowest on the factor.

As shown in Figure 1, the results are highly oriented toward ***Vinyl*** siding on all four factors. Vinyl has the highest perceived performance among all materials and is perceived as

strong in all the above factors (all attributes). ***Composite siding*** (includes various wood-based panels including fiber-cement) is perceived to be second best in availability/ timely delivery and cost/price but weakest in terms of dealer terms/sales rep service. ***Composite and Aluminum/Steel*** siding products are perceived equally low on durability/damage resistance. Aluminum/Steel siding is rated weakest on cost/price and availability/timely delivery and better than composite siding on dealer terms/sales rep service.

A Textual Analysis of U.S. Siding Promotion – Manufacturer Perspective

The purpose of this study was to analyze promotional attributes in the siding industry, and to identify high potential competitive space for new siding products. Limited research has been done to identify and quantify product attributes promoted by manufacturers of residential siding materials. To address this void, software-based textual analysis was used to identify and code 30 product attributes promoted by 99 siding manufacturers producing 165 different brands of residential siding. Two data sources were analyzed: 1) siding manufacturer product brochures or Web pages if brochures were not available and 2) siding advertisements in the "Top 6" builder-focused trade magazines, each with circulation over 63,400.

Analysis results indicate that product attributes of *Aesthetics* and *Design flexibility* were promoted most often in brochures / Web pages, while *Design flexibility* and *Company/product reputation* were promoted most frequently in magazine advertisements. Siding manufacturers also emphasized *Quality* and *Warranty*. Examination of promotion within eight different siding material categories (wood, wood composite, stucco, masonry, vinyl, aluminum, fiber cement, and steel) indicates opportunities for effective promotional strategies.

A gap analysis compared promotional frequency in magazine advertisements to promotional frequency in product brochures (or Web pages). Manufacturers tend to promote *Aesthetics* more frequently in magazine advertisements for wood composite and brick siding. *Design flexibility* is promoted more frequently in magazine advertisements for fiber cement and brick siding. *Company/product reputation* for fiber cement and vinyl siding is emphasized more often in magazine advertisements than in product brochures or Web pages.

A Textual Analysis of U.S. Siding Promotion – Gap Analysis – Builders vs. Manufacturers Perspective

Gap analyses of promotional frequency versus builder performance ratings were also conducted. Results suggest unique promotional strategies for manufacturers of different siding materials. For example, builders' poor performance rating for *Ease of installation* for solid wood siding would suggest that manufacturers should address and/or promote installation features. Similarly, the *Easy to maintain* feature was seldom promoted by wood composite siding manufacturers and was rated as a poor performance attribute by builders. Conversely, the gap analysis indicated that wood composite manufacturers are addressing the perception that *Durability* of wood composite siding is worse than for other types of siding material.

Study implications should be helpful to manufacturers seeking to effectively position siding products within the marketplace and to researchers who wish to understand the nature of promotion within the residential siding industry.

CONCLUSIONS

This study analyzed 30 attributes promoted by U.S. residential siding manufacturers. Attributes were further examined within 8 siding material classifications. Gap analyses compared builder performance ratings to promotional frequency by siding material, as well as promotional strategies between magazine advertising and product brochures / Web pages. Overall, siding manufacturers convey the general message to builders that their products have curb appeal, can be incorporated into a multitude of home designs, have high quality, image or status, and are backed by a reputable company and product warranty.

Examination of promotional attributes by siding material classification suggests unique strategies. Different siding materials have distinct features and attributes. Knowledge about these attributes and the competitive advantage of each type of product is the basis of consumer product selection. *Design flexibility* and *Aesthetics* are key product attributes for all types of residential siding. *Design flexibility*, the ability of a siding material to be incorporated within numerous architectural styles, housing designs and siding layout schemes, appears at least once in 75% (188 of 250) of all promotional items. *Aesthetics* is also heavily promoted for all siding products (66.7%). In addition to *Design flexibility* and *Aesthetics*, manufacturers promote particular features within each material classification. Wood composite is the only group that does not frequently promote *Quality*. Solid wood, Wood composite and Steel don't promote *Company/product reputation* as frequently as other classifications. Siding material groups heavily promote the following attributes in addition to *Design flexibility* and *Aesthetics*.

Solid wood:	Cost effectiveness, Quality
Wood composite:	Easy to install, Warranty, Cost effectiveness
Vinyl:	Warranty, Quality, Reputation
Brick / masonry:	Reputation, Quality, Cost effectiveness
Fiber cement:	Reputation, Quality, Full product line, Cost effectiveness
Stucco:	Reputation, Quality, Product integrity
Aluminum:	Quality, Reputation
Steel:	Quality, Strength, Code approval/certification

Results of gap analyses of promotional frequency versus builder performance ratings further suggest unique promotional strategies. For example, builders' poor performance rating for *Ease of installation* for solid wood siding would suggest that manufacturers should address and/or promote installation features. Similarly, the *Easy to maintain* feature was seldom promoted by wood composite siding manufacturers and was rated as a poor performance attribute by builders. A smaller gap indicated that wood composite manufacturers are addressing the perception that *Durability* of wood composite siding is worse than for other types of siding material.

Study implications should be helpful to manufacturers seeking to effectively position siding products within the marketplace and to researchers who wish to understand the nature of promotion within the residential siding industry.

The complete report entitled “A Textual Analysis of U.S. Siding Promotion” may be found in the Appendix (202 pp.).

Durable Wood Composites for Naval Low-Rise Buildings

A Textual Analysis of U.S. Siding Promotion

Siding and Trim Components
Task S2 – Value Proposition for Siding and OSB

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ABSTRACT

The purpose of this study was to analyze promotional attributes in the siding industry, and to identify high potential competitive space for new siding products. Limited research has been done to identify and quantify product attributes promoted by manufacturers of residential siding materials. To address this void, software-based textual analysis was used to identify and code 30 product attributes promoted by 99 siding manufacturers producing 165 different brands of residential siding. Two data sources were analyzed: 1) siding manufacturer product brochures or Web pages if brochures were not available and 2) siding advertisements in 6 builder-focused trade magazines, each with circulation over 63,400.

Analysis results indicate that product attributes of *Aesthetics* and *Design flexibility* were promoted most often in brochures / Web pages, while *Design flexibility* and *Company/product reputation* were promoted most frequently in magazine advertisements. Siding manufacturers also emphasized *Quality* and *Warranty*. Examination of promotion within eight different siding material categories (wood, wood composite, stucco, masonry, vinyl, aluminum, fiber cement, and steel) indicates opportunities for effective promotional strategies.

A gap analysis compared promotional frequency in magazine advertisements to promotional frequency in product brochures (or Web pages). Manufacturers tend to promote *Aesthetics* more frequently in magazine advertisements for wood composite and brick siding. *Design flexibility* is promoted more frequently in magazine advertisements for fiber cement and brick siding. *Company/product reputation* for fiber cement and vinyl siding is emphasized more often in magazine advertisements than in product brochures or Web pages.

Gap analyses of promotional frequency versus builder performance ratings were also conducted. Results suggest unique promotional strategies for manufacturers of different siding materials. For example, builders' poor performance rating for *Ease of installation* for solid wood siding would suggest that manufacturers should address and/or promote installation features. Similarly, the *Easy to maintain* feature was seldom promoted by wood composite siding manufacturers and was rated as a poor performance attribute by builders. A smaller gap indicated that wood composite manufacturers are addressing the perception that *Durability* of wood composite siding is worse than for other types of siding material.

Study implications should be helpful to manufacturers seeking to effectively position siding products within the marketplace and to researchers who wish to understand the nature of promotion within the residential siding industry.

Keywords: siding, exterior cladding, promotion analysis

BACKGROUND

Scant information is publicly available about U.S. manufacturers' promotion of siding material, particularly which attributes are promoted by manufacturers and which are judged important by builders and remodelers.[1] A benchmark study on the siding industry (Stalling et al. 1989) provides a historical perspective of siding characteristics and types of siding materials. Since that study, market introduction of new siding materials has resulted in shifting consumer preferences and changing trends in the siding industry. This study examines present trends and analyzes current promotional attributes in the siding industry.

The U.S. residential siding market includes a diverse array of materials, from traditional siding like cedar, brick, stucco, and vinyl, to newer materials such as wood composites and fiber cement.[2] Various sources estimate annual sales ranging from $8.4 billion (Freedonia Group, 2004) to $8.6 billion (Louisiana-Pacific, 2006) for siding and $12 billion (Principia Partners, 2006) to $12.4 billion (Market Research.com, 2006; Catalina Research, 2006) for siding and accessories. As innovative materials penetrate the market, firms producing traditional products are forced to become increasingly competitive in order to maintain market share. What attributes do siding manufacturers promote most and least often for their products? Are there key differences in attribute promotion among different types of siding materials? Do manufacturers promote similar attributes in their product brochures, Web pages, and trade magazine advertisements? This study employs a non-intrusive means of answering these questions.

Evaluation of promotional materials is one approach to understanding and identifying key product attributes promoted by manufacturers. This study examined two sources of manufacturer promotion of residential siding: 1) product brochures and Web pages and 2) trade magazine advertising directed at builders and remodelers in the residential housing market. There are several key advantages to reviewing manufacturers' promotional materials:

Manufacturers' promotional materials (brochures, advertisements and Web pages) are fairly easy to obtain. They can be retrieved and analyzed in less time and with lower costs than primary data collection via surveys and interviews.

Promotional material analysis is far less intrusive than interviewing or surveying product brand managers; follow-up due to low response rates is not required.

Survey research is subject to common method bias (Podsakoff, et al 2003). Findings may be more objective and less biased than survey results where respondents are likely to

---

[1] Several market research firms sell their studies of the siding market: Freedonia Group: *Siding: US Forecasts to 2008 & 2013*, 2004 ($4100); Catalina Research: *The Siding Industry*, 2006 ($2995); Ducker Worldwide: *U.S. Market for Residential and Nonresidential Wall Cladding Material*, 2003, ($4900); Principia: *Residential Siding Image 2004* ($35,000 subscription); Principia: *Residential Siding & Exterior Trim 2006*, Oct. 2006, $10,000 pre-launch, $12,500 post-launch; Market Research.com, *Siding*, 2000, ($1575);

[2] Fiber cement products have been used for decades in other countries, but are relatively new siding products in the United States.

overestimate the degree of positive product and service attributes they promote for their products. Further, respondents may condition their answers to be socially desirable to investigators.

Promotional vehicles reviewed can be easily contrasted and compared to determine congruency of promotional message by manufacturer and by siding material category.

Study Objectives

Beyond the Stalling et al. (1989) work, little research on promotion in the residential siding industry is available in the public domain. This study was designed to provide a clear understanding of the dynamics of the siding industry, specifically, patterns of competition within the market. Different siding materials have distinct features and attributes. Knowledge about these attributes and the competitive advantage of each type of product is the basis of consumer product selection. Thus, the main objective of the study is to identify the promotional strategies employed by manufacturing companies, and to help manufacturers develop product positioning strategies. Knowledge about market trends and patterns will support siding manufacturers' decisions about whether to improve existing products or to research innovative technologies in order to supply products that will satisfy shifting customer preferences.

U.S. Siding Industry volume and growth

The residential siding industry has experienced continuous growth in the past two decades. In 1983, industry volume was estimated to be 4.02 billion square feet (BSF) and 6.55 BSF in 1993 (GC&A and RISI, 1994). By 1997, the annual quantity of siding material sold exceeded 7 BSF (Pease 1997, p. 60) and by 2003 it increased to 10 BSF (Louisiana-Pacific, 2006). Current residential siding market volume has been estimated at 11.3 BSF. (James Hardie, 2006). See *Figure 1 - Annual Sales Volume Trend (BSF), U.S. Residential Siding*.

The U.S. annual sales market for siding is currently estimated at $8.6 billion (Louisiana-Pacific, 2006) up from an estimated $4.7 billion in 1986 (Freedonia Group, 2004). Independent studies approximate siding and exterior trim to be a combined $12 to $12.4 billion market (Principia Partners, 2006; Catalina Research, 2006, Market Research.com, 2006). The Freedonia Group Inc., a Cleveland-based industrial market research firm, has forecast sales revenue for all U.S. siding to reach over $10.2 billion in 2008 with industry volume growth to be 1.4% each year and sales revenue growth to be 3.9% each year (Freedonia Group, 2004; Girard, 2005). See *Figure 2 - Annual Sales Trend ($billions), U.S. Residential Siding*.

U.S. Siding Market Share by Material

The residential siding material market is diverse, ranging from solid wood and wood composites to non-wood materials like vinyl, masonry, fiber cement and steel.[3] Various

[3] Technically, brick, stone, and stucco are exterior coverings or claddings, not sidings. For purposes of this study, the term *siding* will include all exterior coverings.

sources provide estimates of market share by material type: investor literature provided by siding manufacturers; the National Association of Home Builders (NAHB); the U.S. Census Bureau, Annual Housing statistics; and independent research firms such as Freedonia and Principia Partners. For example, in 2002, according to NAHB[4], vinyl siding comprised about 31 percent of the market followed by fiber cement (18.3%). Other recent estimates suggest that vinyl siding constitutes nearly 40% of the market share in terms of volume (Principia Partners, 2006; U.S. Census Bureau, 2005). Siding sales are led by stucco and related non-brick masonry siding which cost more than vinyl siding on a dollars-per-square basis (Building Products online, March-April 2005).

Figure 3 - Siding Trends in New Single Family Homes reflects trends in the selection of siding material used in newly built homes, as recorded by the U.S. Census Bureau. Percentages are for number of houses completed that used a particular siding material as the primary exterior siding. The “primary” exterior wall material is defined as material covering more than half the exterior wall. Percentages do not reflect sales of siding by volume or dollars. The choice of brick and wood exteriors in new single family homes has declined as stucco and vinyl siding have become more popular. The *Other* category reflects the increasing popularity of fiber cement siding. The Freedonia 2004 study predicts that fiber cement siding will make the most significant gains in total market share through 2008.

James Hardie Building Products and Louisiana-Pacific Corp. siding manufacturers suggest market share percentages by type of material as depicted in *Figure 4 - Louisiana Pacific Corp., 2003 Siding Market Share by Material* and *Figure 5 - James Hardie, 2003 Siding Market Share by Material*. The largest market share, as of 2003, is controlled by vinyl sidings (42% to 49%), followed by fiber cement (13% to 16.6%). Principia Partners estimates vinyl’s current share of the siding market to be just under 40% (Principia Partners, 2006). Both manufacturers estimate that solid wood and non-cement wood composite materials comprise about 17% of the market share, while brick/masonry accounts for nearly 10% of the siding market.

Market characteristics and trends

Siding industry growth in the 1990’s was spurred by strong increases in both new construction and the residential repair and remodeling markets. Future growth in the repair and remodeling sector is expected as housing stock ages (James Hardie, 2004; Tapco International, 2005). The growth during the 1990’s was likely stimulated by low interest rates and gains in personal income which led to a boom in new housing starts as well as increases in the repair and remodeling sector. In addition to the increase in new housing construction during the past decade, the average floor area in a newly built home last year was 2,434 ft^2, up from 1,645 ft^2 in 1975 (NAHB, 2006). Larger home sizes further increased requirements for siding material.

[4] http://www.nahbrc.org/ National Association of Homebuilders Research Center online.

New Home Starts: Although the housing market has been strong during the last 15 years, recent indicators suggest that housing is on a downward swing. Measures of housing affordability continued to deteriorate through mid-2006, sales of single-family homes and condo units have been falling, and both housing starts and building permits moved down further in June (NAHB, 2006). Siding manufacturers are expected to rely more heavily on the residential repair and remodeling market over the next five years as new home construction levels off. *Figure 6 – New U.S. Housing Starts, 1988 - 2006* illustrates the U.S. Census Bureau's Annual estimates of housing units started, based on its survey of permit holders. A start is defined as excavation (ground breaking) for the footings or foundation of a residential structure.

Historical Trends, 1980-2005: In 1982, aluminum and steel led the siding market while brick and wood sidings were generally used less often (Williams 1982). By the mid 80's, wood siding products dominated the new construction market while vinyl led the remodeling market; vinyl represented about 45 percent of the remodeling sector followed by aluminum (22%), wood (3%), hardboard (8%) and plywood (7%) (Green 1986, pp. 26, 27). An increasing array of substitute products, coupled with competitors' aggressive promotional and product service strategies contributed to solid wood siding's decline in market share. Competition increased with vinyl overtaking most of wood siding's market share in the late 80's and early 90's, primarily the result of vinyl's lower installation and maintenance costs. Demand for vinyl surpassed demand for all other siding material between 1985 and 2002. The residential siding market nearly doubled within the last decade. Other materials not listed in Table 1 below, such as fiber cement, brick and stucco, helped satisfy the increase in market demand.

Table 1 - Change in consumption of major siding materials from 1985-1993 and 1994-2002

Siding materials	Percent change in consumption (1985 - 1993)	Percent change in consumption (1994 - 2002)
Vinyl	+110.8%	+3%
Aluminum	-59.4%	N/A
Steel	-31.8%	N/A
Hardboard	-21.4%	-7%
Cedar	-9.6%	-2%
Plywood	-8.5	-2%

Source: GC&A and RISI (1994); James Hardie (2002)

Market forecast

Various literature sources present different forecasts for residential siding market growth. The Freedonia Group has estimated the market to grow to a value of over $10.2 billion by 2008. Principia Partners estimates the combined siding and exterior trim market is currently $12 billion (2006). Catalina Research estimates the 2006 combined siding and accessories market to be $12.4 billion. Siding market forecasts vary due to housing start predictions and underlying economic assumptions.

Market shares of existing siding products are predicted to shift in the next five years as vinyl's dominance is threatened by alternative materials. Comparisons of present market share of siding material categories are presented in Figure 7 – U.S. residential siding material consumption by type, 1994-2010E. Vinyl's market share is expected to plateau with vinyl maintaining a relatively fixed percentage of market share for the next decade. Vinyl manufacturers have made significant efforts to produce high quality premium products and have initiated strong marketing campaigns that should help preserve market share. Fiber cement will continue to be a strong product, increasing its market share to about 20 percent by 2010 (Freedonia, 2004). Market share of brick, steel, solid wood and other products is expected to remain at or slightly below current levels.

Siding material types and their attributes

For this study the highly competitive siding market was categorized into 8 siding material types as shown in *Table 2*. The solid wood category consists primarily of cedar, redwood and pines. Hardboard, plywood, and OSB are examples of wood composite siding materials. Fiber cement siding, a wood and cement composite, has spurred recent shifts in siding market shares. Non-wood siding materials include vinyl, aluminum, steel, brick/stone and stucco.

Table 2 - Siding material categories

Material Category	Products
Wood Composite	Hardboard, plywood and OSB
Solid Wood	Cedar, redwood, pine, Douglas fir
Vinyl	Lap siding and sheet products, molded polypropylene products
Brick/Masonry	Face brick and natural stone
Aluminum	Lap siding and sheet products
Fiber Cement	Lap siding and sheet products
Stucco	One coat and multi-coat systems
Steel	Sheet

Among 23 product attributes (Stalling and Sinclair 1990) that professionals (builders and contractors) seek for siding products, those that ranked highest in terms of importance in determining choice of siding were *beauty*, *appearance*, *weather resistance*, *availability*, *high status image* and *low/easy maintenance*. Texture, color, size variety, natural material, and fire resistance were ranked low in importance by respondents of this 1998 study. Solid wood rated high in appearance and high in status/image but rated low in terms of weathering resistance and ease of maintenance (Stalling and Sinclair 1990, p. 38). Each of the product categories has its own differential advantage. When a customer buys a product he is buying a complete package of benefits including quality, aesthetics, image and other elements to which he assigns value.

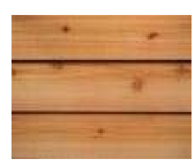
Table 3 and the following discussion section highlight the important material attributes for each of the major siding categories.

Table 3 - Key product attributes for major siding materials

Products	Strengths	Weaknesses
Vinyl	Low maintenance, easy to install, low installation cost, doesn't require painting	Low in status image and appearance, non-paintable surface, can melt/burn when exposed to high heat
Aluminum	Durability, energy efficiency, can withstand high heat, lightweight, can be recycled	Rated low in appearance, lacks status image, expensive to repair, must be grounded to avoid conducting electricity
Steel	Durability, can withstand high heat and hurricane force winds, hides minor wall imperfections, low maintenance costs	High initial cost, rated low in appearance, lacks status image, chalking on paint coatings over time, can be noisy (wind and rain)
Solid wood	Natural, status, paintable/stainable surface, availability	High maintenance and low weather resistance
Brick and Stone	Status, appearance, durability and weathering resistance, insect resistance, energy efficiency, noise reduction	High installation cost, low availability in some areas, can wear and crack
Fiber cement siding	Weathering resistance, low maintenance, good appearance, paintable surface, non-combustible, low cost	Slightly more expensive than vinyl, potential for inhalation of silica dust during installation,
Wood composite	Quality, status image, looks like natural wood, lightweight	Requires periodic maintenance, may shrink/swell when exposed to moisture, less expensive than solid wood
Stucco	Can be painted, availability of various textures	High installation cost, requires skilled labor to install/repair, may develop cracks and bulges

Source: Research and magazine articles, published reports 2004 - 2006

Solid wood

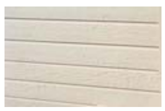


Solid wood in the 80's held about 3 percent of the total market. Cedar, redwood, and pine are the primary species found in solid wood sidings. Although popular in the west, wood sidings generally cater to the upper end of the market throughout the country. They are preferred by the homeowners who are quality seeking. Wood siding is a premium product and is considered a status symbol, which overshadows its characteristic high cost (Shook and Eastin 1996). The largest use of solid wood has been seen in the Northeast and the Western regions of US (Stalling 1988, p.7). Solid wood has been facing competition from other substitute materials because of its high cost and high maintenance properties. It has been reported in many cases that natural wood would always be the preference for the upper end (in terms of

cost) of the market (Wood 2000). A recent study reported that the consumption of wood and wood-based siding products has decreased in new homes from 39 percent in 1978 to about 19 percent in 2001 (Damery and Fisette 2001). Among the solid wood sidings, cedar shakes and shingles and western red cedar were considered most desirable when compared to other wood species like pine (Damery and Fisette 2001). This may be because cedar followed by redwood is considered easier to maintain and more weather resistant than pine.

Wood composites

Hardboard and plywood



In the 1980s, hardboard and plywood were the primary wood based siding materials used in new construction (Green 1986, p. 27). These products were extremely popular in the mid 80's and held 15 percent of the siding market. As reported by Stalling (1988) hardboard and plywood were most popular in the West. These products are durable, easy to apply and low priced compared to the solid wood sidings. They have the disadvantage of weathering when exposed to exterior conditions. Market share has decreased in recent years. Hardboard for siding is made from interfelted wood fibers designed with a specific density to give it a uniform appearance. Hardboard siding is inexpensive and relatively easy to install. Vinyl clad types cost more, but carry guarantees up to 30 years. Other types must be periodically refinished, repainted, or stained.

Plywood siding is most often made of redwood or cedar. It is less expensive to install than solid wood, and comes in a variety of patterns and surface textures. Most plywood siding requires an exterior finish although it is available with preprimed, presealed, or vinyl-clad finishes. Overlaid plywood (MDO) has a surface film especially suitable for painting. Prices for plywood vary from modest for yellow pine and fir to high for redwood and cedar plywood.

Oriented Strand Board (OSB)

Oriented strand board sidings are engineered wood products that are stronger than plywood when dry. These products cost about 30 percent less than all solid wood sidings. OSB has the negative property of mildew and moisture retention that leads to vast decrease in strength thus making it less desirable than other products in its application as a siding material.

Shingles and Shakes

Shingles and shakes are durable wood composites that add texture to a house. Like other wood sidings, shingles and shakes may be allowed to weather naturally, or can be stained or painted. Material and installation costs of shingles and shakes are higher than for some other sidings. The most expensive shingles and shakes are constructed from more durable species, like western red cedar.

Particleboard Siding

Overlaid particleboard siding consists of a particleboard core, overlaid on both sides with a resin-impregnated fiber sheet. Most manufacturers recommend a paint finish for

overlaid particleboard. Particleboard siding may have to be repainted periodically as needed.

Wood Plastic Composite

Boise's HomePlate product was to be the first wood-plastic siding material offered commercially. While it isn't extruded, the materials are a wood plastic composite--HDPE and reclaimed wood fiber. "We're very competitive with fiber cement in our on-the-wall cost," says Mike Moser, building solutions communications manager for Boise. "We have less waste, and it's easier to back cut and notch." He says the reason other WPC makers haven't offered siding is technological. HomePlate, as of this writing, was not available for purchase (2005).

Wood fiber-plastic composite technologies under development at Washington State University are poised to compete directly with fiber cement and vinyl siding in this lucrative market. Vinyl siding manufacturers are diligently demanding an extrusion technology to meet the fiber cement challenge in the market place.

Vinyl

One of 2005's most financially rewarding outdoor projects for homeowners was installation of new vinyl siding and trim. The average national cost of replacing 1250 square feet of siding was $6946. The average value added was $6445 (Brenner, 2005).

Vinyl siding was introduced in the early 1960s. In the 1970s and 1980s, the vinyl industry made numerous improvements in formulation to speed production, add colors, and improve weathering and resistance impact. By the mid 1980's vinyl siding held about 45 percent of the remodeling market, surpassing aluminum siding (Green 1986, p. 26). Vinyl sales continued to increase in the 90's, capturing more of the wood, aluminum and steel markets. According to NAHB, vinyl siding represented about 31 percent of the 2002 siding market.[5] Other estimates place vinyl siding's market share between 40% and 49% (Principia Partners, 2006; James Hardie, 2004; Louisiana-Pacific, 2006). The popularity of vinyl siding was due primarily to its low cost and reduced maintenance requirements. Its major strengths include low installation cost, realistic grain patterns, color availability, durability, no need for painting, and ease of installation. One problem noted by some builders is vinyl's tendency to warp and crack (Milano 2001 p. 116). PVC (polyvinyl chloride), the major component of vinyl siding, is susceptible to ultraviolet degradation and expands and contracts significantly.

Through its introduction of high-definition polypropylene siding, Nailite brought the technology of injection molding to the siding industry and continues to be a leader in this specialty class of siding. To achieve the appearance of real wood, such as shaker-style shingles, the siding must be molded from polypropylene, a more expensive plastic. In 2002, molded polypropylene siding (MPS) was estimated to be a $120 million market, or

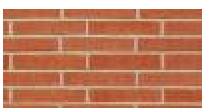
[5] http://www.nahbrc.org/ National Association of Homebuilders Research Center online.

approximately 1.5% of the siding industry. MPS has grown more than 13% per annum over the past two years. Nailite, Tapco (Foundry), and Certainteed molded polypropylene products are classified in this siding study as vinyl. Principia Partners predicts vacuum-formed vinyl panels will begin to compete with molded polypropylene siding.

Fiber cement

Fiber cement siding has grown dramatically in the U.S. during the last decade. Although fiber cement technology has been around for more than a century, mainly in Europe, its popularity as a siding product has been more recent in North America. Fiber cement siding can resemble stucco, wood clapboards, or cedar shingles. The fiber cement siding product's appeal lies in its improved properties over traditional siding materials. Unlike traditional siding products, fiber cement siding is generally more resistant to moisture, termites, fire and other elements that reduce the lifespan of wood (Porter 1998). Additionally, fiber cement siding products are like wood in appearance and show an improvement in terms of appearance as compared to vinyl sidings. Fiber cement siding eliminated mold problems associated with hardboard siding. It is marginally more expensive than vinyl and slightly heavier than wood (McLeister 1997, p.86). The product's appeal is its low maintenance. Numerous sources purport that because fiber cement does not warp, bend or crack, it offers a better surface for paint as compared to wood and vinyl (Milano 2001 p. 116). Tests have shown that paint holds to about 8 years for fiber siding as compared to 5 years for wood siding (McLeister 1997, p 86).

Brick / masonry



Brick, natural stone, and synthetic stone siding products are the most durable siding products. They also rank high on aesthetics, maintainability and status but are the most expensive siding material, and can cost nearly 10 times the cost of vinyl. Genuine clay brick and stone have been used as siding for centuries. They rate high in appearance, offering a variety of types, textures, and colors. Brick and stone houses are quiet inside. They are weather/fire/wind/insect resistant. Brick and stone sidings don't require additional factory finishes. The downside of masonry exteriors is their higher installation cost. Siding or re-siding with brick or stone is expensive and requires a skilled mason.

High shipping costs usually limit the use of stone siding for home construction to what is available in a particular area. Recent cultured stone sidings are less expensive than their previous counterparts, the natural stone sidings. They are made from natural ingredients and imitate the size, shape, texture and look of the regional stones, but cost and weigh less. Manufactured or synthetic stone is a combination of cement, light-weight aggregates, and colored oxide. High quality manufactured stone is difficult to distinguish from real stone. Availability of manufactured stone may be limited. As with natural stone, installation costs are high.

Stucco

The market for stucco siding has remained relatively stable over the past 20 years (see Figure 7 – U.S. residential siding material consumption by type, 1994-2010E). Stucco is predicted to maintain its market share of about 8 percent. Traditional stucco is normally used on Mission or other Spanish style homes.

Installing stucco is expensive, and installation and repair require skilled labor. The finish coat can be pebbled, textured or smooth and may be colored by the mason. Stucco does not require painting. Routine maintenance is easy and consists mainly of repairing small cracks. Stucco siding can crack if the house settles, allowing water to penetrate the walls necessitating immediate repair. Many homes built after the 1950s use a variety of synthetic materials which resemble stucco, such as EIFS (Exterior Insulation and Finish Systems).

Aluminum

Aluminum exterior cladding, introduced as the first maintenance free siding, originally appeared on houses in the 1950s. Though aluminum siding was invented for use as a new construction material, its greatest application was in home repair and remodeling. The 1960s and 1970s were boom years for aluminum siding, but it continued to be used mainly as remodeling material. Despite the introduction of vinyl siding in the early 1960s, aluminum maintained its hold on the siding market until the early 1980s, when vinyl took the lead in sales. Aluminum held market share of 22 percent in the remodeling market by 1986 (Green 1986, p. 27), but sales dropped significantly beginning in 1987. Aluminum siding’s strengths were its light weight, durability, and low maintenance. Most of aluminum’s market share in the last two decades has been consumed by vinyl. By 2000, aluminum held only about 1 percent of the residential siding market. Its major disadvantage is its tendency to dent and fade under extreme conditions (Milano 2001, p. 116). Aluminum siding’s baked finishes are similar to car finishes and will fade and weather over time and can be repainted. Aluminum siding can be recycled.

Steel

Steel was a primary siding competitor in the mid 80’s in the Midwest and southern regions of the U.S. Its introduction as a siding material was triggered by builders’ search for a ‘different kind of product’ (Green 1986, p. 27). Seamless steel siding has the strength to withstand significant changes in temperature and to resist hurricane force winds. Steel siding can be fused with a top coat of PVC to provide a low-gloss finish and color-fast texture. Unlike vinyl, steel is able to hide minor wall imperfections. Steel resists dents, but hard blows can dent the siding or chip its finish. Steel risks rusting from cuts. Like aluminum, steel’s factory-applied finishes are similar to car finishes and will fade and weather over time but can be repainted. Steel siding is more expensive than vinyl siding.

Decision-making process in residential siding

Purchase decisions in residential siding are influenced by many product and market factors such as cost, installation requirements, and appropriate information dissemination by manufacturers. The decision-making process is complex and the factors influencing the decisions vary among groups of contractors, architects, and homeowners. Successful promotional strategies depend on a thorough understanding of this decision-making process.

Recommendation by builders

Most research on siding (Damery and Fisette 2001, RSI 2004, Stalling and Sinclair 1989) has recognized the weight of the builder recommendation in the homeowner choice of siding materials. Further, all relevant studies have been based on the perceptions of builders and have indicated that recommendation from builders is influential in at least half of the purchase decisions made for siding.

A recent study of siding in 12 northeastern U.S. states reported that “builders and architects appear to be the key decision makers regarding siding… However, both architects and contractors think that homeowner opinion is an important consideration.” (Damery and Fisette 2001). Stalling and Sinclair (1989, p. 64) reported that of the total decisions made, builders specified the type of siding more than 50 percent of the time. Homeowners selected the type of siding 28 percent of the time, and about 10 percent of the siding decision-makers belonged to each of the architect and developer category. Developers play the most important role in the decision-making process in multifamily construction (Stalling and Sinclair 1989).

Literature on purchase decisions for siding recognizes that decisions of the homeowners depend largely upon recommendation from builders, followed by product pricing, product performance and brand name recognition. The RSI State of the Industry Report 2005 (Russo, 2004, p. 8) reported that 60% of contractors surveyed believe contractor reputation/opinion has the most impact on siding purchase decisions.[6] Price was the second most important factor affecting purchase decisions (24% of the contractors) while contractors ranked product performance and appearance as the third factor (6 %).

Table 4 - Basis of purchase decisions by homeowners (responses by % of builders)

Decision factors	1998	2000	2004
Recommendation of builders	50%	47%	60%
Price	36%	42%	24%
Product performance, color, style	9%	9%	6%
Brand name	5%	2%	unreported

Source: RSI 1998, 2000b, 2004 State of the Industry Reports

[6] RSI magazine has 23,600+ subscribers of which 8800+ are siding contractors. All subscribers are polled; however, response rate was not available.

Pricing and Installation Cost

Price has been cited as one of the top 3 factors in selection of siding (Damery & Fisette 2001, RSI 2004). Roofing, Siding and Insulation magazine (RSI) asked contractors to rank the three most important factors when their customers make buying decisions regarding siding (Table 4). Price was ranked as the second most important factor (24%). Total installation costs must be considered rather than price of material alone. Installed cedar shingles, masonry and stucco cost more than other materials; hardboard, plywood, vinyl and aluminum siding are relatively less expensive to purchase and install.

Affordability/economy is defined by purchase price, installation costs, and maintenance costs. Installed cost of siding includes price and all labor to install. *Figure 8 - Siding Installed Cost Comparison* provides a comparison of the 2005 installed cost of siding materials. Costs are averages and may vary widely by numerous factors such as geographic region, proximity to manufacturers, availability of skilled labor, and economy vs. premium materials. Exterior Insulation and Finish Systems (**EIFS**)[7], also known as synthetic stucco or Dryvit, appears in Figure 8 but was not included as a separate siding material type in this study. Dryvit siding was categorized as 'stucco' in this study.

Product performance, color and style

Initial cost may be an important factor for making purchases but life cycle cost (operating and maintenance) is significant as well, making product performance a key factor in selection of siding. For example, a preference for wood siding is overshadowed by its perceived high maintenance costs (Shook and Eastin 1996). Damery and Fisette (2001) also looked at key attributes that influence the purchase decision of siding materials in the northeastern U.S. Their study reported *appearance* and *performance* to be the two most important factors affecting choice of siding for architects, contractors and homebuilders alike.

The vast array of siding materials indicates an ongoing search for an optimal product that meets all performance standards. Companies are introducing new siding color choices and textures. The interest in different siding colors has created an opportunity for paint manufacturers to introduce pant formulations suitable for each siding material.

Because of the differences in architectural style, siding profiles vary considerably. Lap siding, panels (double 4, double 5, 8 inch), shakes, tongue and groove, Victorian profile (boards of 2 and 21/2 inches), bevel and ship-lap are common types of profiles.

Brand positioning

The importance of brand name has been recognized by literature in all industries. Branding creates awareness with the aim of generating an emotional-impulse response

[7] EIFS are multi-layered exterior wall systems that typically consist of three layers: a foam insulation board, a water-resistant base coat reinforced with glass fiber mesh, and a textured finish coat.

from customers. Brand positioning is the creation of a precise focal point around a product's most significant competitive difference and planting that difference firmly in the minds of potential customers. Positioning implies the inherent weakness of competing products by comparison.

Traditionally, the forest products industry has been production oriented and thus, brand name was not considered an important factor for commodity products. With the industry becoming more customer-oriented, manufacturers have realized the importance of product differentiation in terms of brand name. For example, James Hardie Building Products and Certainteed are fiber cement manufacturers using their names to market their siding products. In a 2006 brand use survey sponsored by *Builder* magazine, builders were asked to rate the brand names of different siding products that they had heard of most frequently. The 2006 Brand Use Study illustrates awareness of top brands of siding materials. The top three brands recognized by builders (3853 respondents out of 10,800 builders, 36% response rate) for the last two years are summarized in the table below.

Table 5 – 2005 Siding Brands heard of most frequently by US builders (n=3,853)

Siding type	Brand recognition (% who heard of each)
Brick	1. Boral (31%) 2. General Shale (26%) 3. Acme (19%) 4. Hanson Brick (19%)
Stucco	1. Dryvit (54%) 2. U.S. Gypsum (43%) 3. Senergy (17%)
Fiber-cement	1. James Hardie (Hardiplank) (74%) 2. Certainteed (Weatherboards) (38%) 3. Nichiha (3%)
Insulated	1. TrueComfort (22%) 2. CedarMax (13%) 3. Structure (13%)
Vinyl	1. Certainteed (58%) 2. Owens Corning (45%) 3. Alcoa (45%)
OSB	1. Georgia-Pacific (72%) 2. LP Smartside (22%) 3. ABTco (13%)

Source: 2006 Brand Use Study, Builder magazine, a Hanley-Wood Publication

These manufacturers are just a few of the primary competitors in the siding industry. The industry includes a gamut of small and medium sized firms who endeavor to identify a niche for their products. Brand awareness and appropriate positioning of siding materials is a crucial marketing tool.

End use

Like most building materials, siding material market characteristics depend upon end use. Siding industry market statistics vary depending upon structural end use: single/multi-family construction, residential or commercial, new construction or remodeling. Geographical factors and local housing prices also influence siding selection. The following 3 factors form the basis of market segmentation in residential siding:

1. Repair and remodeling or new construction (single or multi-family house construction).
2. U.S. census regions (e.g., metropolitan areas, states, regions, etc.).
3. Housing price points (e.g., upper, middle, lower within markets).

In terms of revenue, multi-family home builders are the largest consumers of siding materials, followed by single-family home builders, siding contractors, and repair/remodeling contractors. Regional preferences and housing prices also factor into choice of siding products.

Paintability

One characteristic that has been gaining increased attention is the “paintable” feature for exterior products. Exterior products like siding and windows face problems of peeling and fading, and homeowners are anxious about repainting surfaces. There is little information available to customers about the best surfaces to paint and what kind of paint is best suited for each type of siding. To answer these questions, it is necessary to learn about paints and their basic characteristics. The three major ingredients in any paint are the following:

1. *Pigment*: The component in paint responsible for opacity, color, and degree of gloss. Pigments are usually in the form of dry powder and can be organic (containing carbon), inorganic (no carbon), synthetic or natural.
2. *Binder*: The component that holds the pigment together. Binders consist of synthetic or natural resins that start out as liquids but gradually thicken to form tough films. In water-borne coatings, the binder is usually a latex emulsion comprised of vinyl or acrylic co-polymers. In solvent-based coatings the binder is typically an alkyd, a natural drying oil modified chemically to be long lasting. Over the years the use of solvent based binders has diminished because of volatile organic compounds present in them. In many cases the solvent borne paints provide a better quality than their waterborne counterparts. These include rust inhibitive primers and other special primers like stain blockers, stains such as wood stains for furniture decoration and exterior semi-transparent finishes, and varnishes which are transparent finishes
3. *Solvents* (thinners and dispersing agents): These evaporate after application to give a film of bonded pigment.

Other ingredients may include thickening and anti-settling agents as well as fungicides.

Paints can be differentiated in terms of the following:

1. Exterior and interior
2. Degree of gloss (high gloss, low luster, egg shell, low gloss, satin, flat)
3. Quality
4. Color- The color trends show a move away from the traditional gray colors to cleaner, luminous more light-infused colors (Benjamin Moore and Co.). Blue-green, bottle green, frosted glass, lighter blue, mauve and red are likely to dominate.
5. Alkyd (resin binder) and latex (acrylic and vinyl binder)
6. Paints and stains
7. Primer, undercoat and topcoat (alkyd/oil based and water based)
8. Specialty coatings
9. Size of container (0.945 liters, 3.78 liters and 18.9 liters)
10. Product lines

Considerations when buying paint include:

1. Color
2. Ease of application
3. Protection against weathering
4. Product quality: With sound surface preparation a good quality exterior paint can last up to 8-10 years.

Surfaces for paints:

1. Wood and wood based siding: Although any paint can be used that has been recommended for houses, latex paints significantly reduce the application and drying time. A primer, a sealer and an undercoat are required. Surfaces should be primed with latex exterior primer for proper adhesion to the topcoat. The open spaces should be caulked and the cracks and splits should be repaired.

2. Masonry siding (Brick, cement, stucco, cinder block, asbestos cement): Almost all exterior latex paints can be used for the masonry surfaces. For brick, finish such as clear water repellant coating can be used.

   a) New surface – The concrete should be allowed to dry and the surface should be cleaned of all dirt, grease and dust. A block filler should be applied to close pores and for a smoother surface.

   b) Old painted surface – The surface should be cleaned of dirt, dust and grime. Loose and peeling paint should be removed.

3. Aluminum siding: The surface of aluminum is likely to corrode with time. Along with the paints, corrosion inhibitive primers have to be used.

4. Steel siding: Steel sidings like other metals are prone to rust under exposure to moisture conditions. Rust inhibitive primers have to be applied in addition to the enamels and paints for prevention

5. Vinyl siding: Vinyl sidings do not need painting because they occur in many colors themselves. Vinyl siding like other plastics are difficult to paint but research and development may probably soon see a breakthrough that could remove this disadvantage.

A few research questions that could be addressed are as follows:

1. Which siding material type is the best surface for painting?
2. What critical paint attributes (cost, color, quality, brand, ease of application, maintenance) are important to homeowners?
3. What type of paint is preferred (oil based or water based) for each siding material type?
4. What are the best paints to use, in consumers' opinions, for different siding materials?
5. What are consumer color preferences?
6. What are the best primers and sealers for the paints?
7. What other additives are necessary to paint each siding material type?
8. What are consumers' concerns about paints for sidings and exterior applications?

Marketing communication mix

Siding manufacturers utilize a variety of promotional tools. One objective of this study is to analyze different promotional materials that influence the consumer's choice of siding materials. Proper communication with customers increases awareness of products, new uses, salient attributes, and product enhancements. Wood products have experienced losses in siding market share due in part to poor promotion and positioning strategy. Product promotion strategies are influenced by threats from substitute products. To recognize and understand a market share threat, manufacturers need to know how customers perceive their product in comparison with the substitute product for given attributes. For example, solid wood siding and brick compete in terms of appearance. Differential advantages of each can be effectively communicated to customers through promotional materials.

Communication mix components

The **marketing mix** approach to marketing is a model of specifying and implementing marketing strategies (Borden 1964). It stresses the "mixing" or combination of various marketing strategies and plans in such a way that both organizational and consumer objectives are attained. The most widely recognized variables used in constructing a marketing mix are the four P's: price, promotion, product and placement (also called distribution). This study focuses on the communication mix, a 'sub-mix' of the marketing mix model.

Communication mix or *promotional mix* are terms used to represent a combination of four different promotion programs – advertising, personal selling, sales promotion and public relations. A fifth more recently recognized component of the promotional mix is *E-marketing*, a type of marketing that can be defined as achieving objectives through the use of electronic communications technology such as Internet, e-mail, database and mobile phone (Smith and Chaffey, 2005).

Different companies may use different mixes of promotional tools to achieve their objectives. The major objective of the industrial firm's communication mix is to provide persuasive information about the company and its product-service mix to its customers. The following section details the different communication mix components.

Advertising:

Advertising is mass communication directed at a large number of potential customers. It is an effective way to reach a geographically dispersed population at low cost per exposure. Advertising builds brand awareness. Advertisements for siding products typically appear in trade journals like *Builder, Professional Builder*, *Remodeling Contractor* or *Wood Technology* and in magazines like *Home Improvement* and *Fine Homebuilding*. The type of promotional strategy used for advertising depends on the use of the product and the attitude of customers toward the product. Advertising is used by the forest products industry to differentiate wood products from other substitute products such as solid wood siding versus vinyl or masonry.

Personal selling:

Personal selling has been defined as direct communication of information about a company's product or service offering between salespeople and customers. It may be face-to-face or via telephone. Mater et al. (1992, p. 181) reported that about 70 percent of industrial products are sold by personal selling as compared to 48 percent of consumer products. Personal contact develops customer loyalty and encourages repeat purchase decisions.

E-marketing:

The term e-marketing, coined by David Chaffey (Smith and Chaffey, 2005) includes digital technologies such as Web, e-mail, online databases, and mobile/wireless communications aimed at marketing activities. Demand for the Internet as a promotional tool is increasing at a phenomenal rate; online media has become an integrated component of the total marketing mix for many retailers and manufacturers. Siding manufacturers' promotion of innovative siding materials can be found on numerous manufacturer, retailer, and supplier Web sites. Many siding manufacturers, for example Certainteed and James Hardie, also use electronic catalogs for promotion and as a source of information for homebuilders and homeowners.

The Home Depot retailer has begun selling advertising on its Web site, including streaming video ads, to manufacturers. The retailer promotes the fact that Home Depot's online store is visited by 4 million shoppers each week. Users can click on the ads to link directly to the manufacturer's branded site.

> *"Our vendors can definitely do much more online than with their in-store displays," says Greg Foglesong, director of Web marketing and sales at Home Depot in Atlanta. "Vendors can communicate their stories of innovation, and new product selection via video."*

Home Depot also plans to sell advertising on its e-mail newsletters, which go out to more than 6 million subscribers. (HomeDepot.com, http://ir.homedepot.com/releasedetail.cfm?releaseid=204075)

Sales promotions:

Sales promotions are short-term communication activities other than advertising and personal selling to encourage purchase of a product or service or to build strong relationships with the industrial distributor or customer. Popular sales promotions include coupons, rebates, contests, premiums, free samples, point of purchase display materials, and trade shows.

Trade Shows: Trade shows in particular are used frequently in the forest products industry. A trade show is a type of promotion organized by a trade association or a professional group (sponsor) which invites companies to open booths to display their products to interested customers. Trade show expenditures are the second largest item in the business marketing communications budget after advertising, accounting for nearly one-fifth of the total budget for U.S. firms (Centre for Exhibition Industry Research, www.ceir.org). Trade show incentives to manufacturers include: meeting potential customers, compiling a mailing list, introducing new products, building company image, locating new dealers and representatives, generating sales leads, and collecting feedback from customers.

Virtual Trade Shows: Trade show sponsors are incorporating the E-marketing component of the communication mix. Virtual Tradeshows (VTS) are online industry events where manufacturers and customers can exchange ideas and preview new products and services. Using a variety of web technologies, the VTS presents multiple vendors in one online "exhibition hall". The VTS may include online keynote presentations and panel discussions. Like traditional trade shows, they offer marketers a means of communicating with a large number of targeted customers in one location, but at a fraction of the cost of live trade shows. Virtual Trade Shows can't replicate the buzz and advantages of face-to-face contact of live trade shows, and may often be used to supplement traditional trade shows.

The International Builder's Show (IBS) introduced its Virtual Trade Show in 2001. It is the digital search system that allows attendees to locate company and product information at the live trade show. The IBS further offers exhibitors the ability to create and maintain their own "Virtual Booth" to be included in the online search system, available online to attendees for 1 year. Each virtual booth is maintained by the manufacturer/exhibitor and may contain marketing and sales information as designed and controlled by the exhibitor. The 2007 cost of a Virtual Booth to IBS exhibitors is $150 (http://www.buildersshow.com/Exhibitors/BecomeAnExhibitor.aspx).

Public relations/publicity:

Publicity is the use of information and the communication of that information through a variety of media to influence public opinion. Publicity is a form of mass communication directed toward the customer at no direct cost to the manufacturer. It may include news items, technical articles, sponsorships, seminars or online information about a company. News items are highly credible and can reach potential customers who try to avoid salespeople and advertisements (Kotler 1997. p. 623). Building product manufacturers frequently reach customers via technical articles in trade journals and magazines.

Siding Promotion

Traditionally, siding manufacturers have employed the following vehicles to promote their products: direct mail, catalogs, trade shows, limited television advertising, and advertisements in housing and home magazines, trade journals, and newspapers. Most large suppliers also now use the Internet as an additional promotional medium.

In a recent study on siding selection (Damery and Fisette 2001), emphasis on product name and reputation was reported as an important promotion and information tool. Besides reputation, the customer's own knowledge was reported as a relevant source of information for choice of siding. Although the results of the study indicated that advertising was not a crucial source of information, it is still considered an indirect medium that may form the basis of knowledge for consumers. Advertising of siding products was more important for contractors and homeowners than architects (Damery and Fisette 2001). Magazine and technical articles were found to be a preferred source of information for siding choice as opposed to advertising.

This study will examine two promotional vehicles to categorize product attributes by siding material type: 1) Web pages and product brochures, and 2) builder magazine advertisements.   Differentiation of products focuses on the product's unique features and provides a measure of protection against its competitors. Some of siding's differential attributes that are the focus of promotion materials are summarized in the table below.

Table 6 - Siding product attributes promoted in the market by suppliers

Siding Product	Attributes
Vinyl	Low maintenance – impact / insect resistant, low cost, durable, warranty, color variety, no painting requirement, easy to apply, appearance and texture like wood, brand names
Brick / masonry	Natural look, high status image, extremely durable, no paint requirement, low maintenance, availability in many textures and colors, excellent insulation
Wood	Natural appearance, availability in various styles, sizes and natural colors, good paint surface, brand name
Stucco	Can be painted, availability of various textures, durable
Fiber cement	No weathering, resistant to insects, variety in colors and style, no rot crack like vinyl, appearance of wood with wood grains, variety in sizes, brand names
Aluminum	light weight, durability, low maintenance
Steel	strength to withstand significant changes in temperature and to resist hurricane force winds; hides minor wall imperfections
Wood Composite	durable, easy to apply, low priced compared to the solid wood sidings
Hardboard, plywood	Wood base and appearance, variety of colors, less expensive than wood
OSB	Appearance close to solid wood, size, texture, warranty, stable, consistent and light, resistance to insects and fungal decay, price relative to wood

Source: Supplier advertisements in different promotional media

The 2004 RSI State of the Industry Report stated that siding customers were looking for improved customer service and communications. Almost 20% were looking for supplier support as it relates to guarantees, education and training. "Suppliers could upgrade and send their latest advertising brochures so we have appropriate information to share with our customers," said one remodeler (Russo, RSI 2004). RSI further reports increases in the siding contractor's use of the Internet.

> *Only 31% of siders—and 30% of residential contractors overall—have put up a Web site. However, 64% of those grossing more than $1 million annually have a site, which is equal to the percentage of commercial roofers up on the Internet. In addition, 68% of siders said they use the Internet themselves for business purposes—a big increase of 18% this year. (Russo, RSI 2004)*

Selection of a promotional strategy

The right promotional strategy depends upon the objectives of the manufacturer. The promotional mix is influenced by whether the manufacturer is using a push strategy or a pull strategy or a combination of both for marketing its products.

Push promotion strategy: A push strategy is directed at the distribution channel. It attempts to motivate the channel intermediaries with trade discounts, cooperative advertising allowances and other incentives as motivation to push the product to the customers. In this case, the manufacturer relies heavily on personal selling and trade promotion to induce the wholesaler and retailers to carry their products and to subsequently push the product to the customers.

Pull promotion strategy: A pull strategy has as its goal stimulating demand from the customers through sales promotion and advertisement to encourage them to pull the product off the retail shelf. The demand of the product is estimated to grow so the customer is expected to ask the distributor for the product, who asks the manufacturer for the product. Thus, the product is pulled from the manufacturer through the distribution channels to the customer.

The promotional strategy that is used by the manufacturing firms to increase the sales of their products integrates advertising, sales promotion, public relations and personal selling to form a promotional mix. Taken together, the ‘push’ and ‘pull’ strategies hold the key to manufacturers’ power over the distribution demands. Determining whether push or pull is the appropriate strategy or whether integrated promotion strategy should be followed depends on the market, the distribution channels, and the product that is of interest.

Promotional tools vary in their cost effectiveness at different stages of the product life cycle as shown in Figure 9 - Cost effectiveness of different promotional tools at different life cycle stages. Kotler (1997, p. 628) reported that at the introduction stage of the product life cycle, advertising and publicity are most cost effective followed by personal selling and then sales promotion. In the growth stage demand is based on word of mouth. In the maturity stage all three tools grow but in different orders. Sales promotion is more important than advertising and publicity, which is followed by personal selling. In the decline stage where all the tools reduce, sales promotion still continues strongly but advertising and publicity and personal selling are reduced as consumers pay minimal attention to the product

Integrated Marketing Communications (IMC): Many companies still rely on one or two tools of promotion. Recently, a growing number of companies are also using the concept of integrated marketing communication for promoting their products. Integrated marketing provides an opportunity to improve the effectiveness of promotional programs by handling all aspects of promotion through a single source (Linton and Morley 1995). In integrated marketing communications all communication activities are channeled through a

single coordinator and handled by a single agency. Integrated marketing communications maximizes resources by linking the different communication activities directly with the organizational goals and the resulting bottom line (Gonring 1994, p. 45). The key benefits are consistency of message, better use of all media, greater marketing precision, operational efficiency, cost savings, consistent service, better working relations and unbiased marketing recommendations.

In some cases, a single promotion tool will produce the desired effect and in other cases, full integrated marketing communications are needed. Different promotional tools from the mix should be used for specifically targeted customers. For example, direct mail can be used for homeowners and DIY’ s and trade journals and magazines could be used when targeting builders.

METHODS

The traditional approach to collecting promotional data about building materials has been to survey manufacturers, builders, architects and/or consumers. Data collection via surveys and questionnaires may require any or all of the following: extensive exploratory interviews, development of hard copy or electronic questionnaires, pre-testing of questionnaires, pre-notifications, postal costs if mailing questionnaires and notifications, incentives to increase response rates, follow-up mailings, follow-up phone calls, and handling of non-responses. This study employs a novel approach in data collection and methodology that diminishes non-response, reduces respondent bias, is less intrusive, and mitigates the time and cost associated with traditional data collection via surveys and questionnaires.

Qualitative Research and Grounded Theory

Qualitative research and analysis methods employed by management science scholars provide an adaptable template for examination of siding promotional materials. In particular, *Grounded Theory* is a qualitative research technique that seeks to relate the usage of categories of text in order to develop abstract models of social phenomena (Glaser & Strauss, 1967; Corbin & Strauss, 1998). Two key analytic components occur simultaneously when employing grounded theory techniques:

1) the researcher constantly compares and contrasts data and theory during data collection and analysis;
2) using theoretical sampling, the grounded theorist decides which additional data is relevant to development of evolving categories and concepts.

Systematic coding procedures support ongoing comparisons of data and theory. Grounded theory may also utilize quantitative techniques during theory development. The major difference between grounded theory and other qualitative techniques is its emphasis upon theory development.

> *"Grounded theory is a general methodology for developing theory that is grounded in data systematically gathered and analyzed. Theory evolves during actual research, and it does this through continuous interplay between analysis and data collection."* *(Strauss & Corbin, p. 158).*

The majority of early work by grounded theorists was in the field of sociology. Examples of sociological applications of grounded theory include remarriage after divorce (Cauhape, 1983) and experiences with chronic illness (Charmaz, 1980). Later work in areas of psychology, anthropology and education followed. Increasingly diverse types of research fall under the umbrella of grounded theory.

> *The diffusion of this methodology seems recently to be increasing exponentially in numbers of studies, types of phenomena studied, geographical spread, and disciplines (education, nursing, psychology, and sociology, for example). The diffusion of grounded theory procedures has now also reached subspecialties of disciplines in*

> *which we would not have anticipated their use – and does not always appear in ways that other grounded theorists would recognize as "grounded theory." For instance, there are studies of business management, communication studies concerning such areas as the use of computers by the physically disabled, and "grounded theory" applied to the building of a theoretical model of the epistemology of knowledge production.*
> *(Strauss & Corbin, Grounded Theory Methodology, p. 166)*

Our study of the promotional attributes of siding products is an adaptation of basic grounded theory techniques combined with quantitative analysis methods. The application is non-traditional in that it doesn't apply to typical social and behavioral science disciplines, but to marketing and management sciences. The ongoing development of a 'theory' (i.e., identification of promotional attributes for different siding materials) and the use of software-aided textual analysis to identify categories within documents are techniques employed by grounded theorists.

Software Textual Analysis

The term '*Qualitative data analysis'* describes a wide range of methods for handling rich data records such as text, sound and images. A prevalent and growing component of qualitative data analysis is the use of Computer Assisted Qualitative Data Analysis Software (CAQDAS). Numerous software packages are commercially available to assist researchers with qualitative data collection, storage and analysis. The primary function of these software packages is in data marking, storage and retrieval. While many CAQDAS products offer additional levels of complexity, the concept of programmatically coding textual data is the building block of these products. Text segments found in documents such as promotional advertisements, interview transcripts, notes and voice recordings are tagged categorically by the researcher. The software facilitates the attachment of codes to text strings, and allows the researcher to retrieve and analyze text by code categories. The basic logic of coding and retrieving text segments is no different than traditional manual approaches such as physically marking text segments with codes or different colors of ink, but the computer offers obvious advantages such as speed and complexity of searches, combinations of codes, and the ability to efficiently handle large amounts of data.

Many CAQDAS packages provide additional levels of sophistication such as attaching notes to specific points in the text, linking multimedia to data, visual display matrices of nodes, or the ability to perform quantitative data analysis on tagged data. "The computer-based handling of textual data is a useful extension of the capacities of word-processing and textual data storage. The indexing or coding of text in that context is a useful heuristic approach to the data themselves." (Coffey, Holbrook & Atkinson, 1996).

NVivo Software

This study employed QSR International's NVivo 2.0 software to store and tag textual data from siding magazine advertisements, Web pages, and product brochures collected for this study.

> **NVivo** is designed for researchers who need to combine subtle coding with qualitative linking, shaping and modelling. A fine-detailed analyzer, NVivo integrates the processes of interpretation and focused questioning. Rich text records are freely edited and coded and linked with multimedia. A project starts as soon as ideas start. NVivo enables you to take qualitative inquiry beyond coding and retrieval, supporting fluid interpretation and theory emergence.

http://www.qsrinternational.com/products/productoverview/NVivo%20brochure.pdf

Application and use of NVivo software was taught in Qualitative Research Methods courses at Pennsylvania State University. NVivo was selected due to the researcher's familiarity with the software.

Promotional items were from one of two sources: 1) magazine advertisements and 2) product brochures or Web pages. Two separate NVivo projects were created, one for magazine ads and one for product brochures / Web pages. All text found on each promotional item was scanned and then imported into NVivo. The researcher used NVivo to attach codes to text strings, identifying appropriate strings with one of 30 attribute codes.

Quantitative Analysis

Following completion of all data entry and coding, two databases were produced: one for magazine advertisements and one for product brochures / Web pages. Each record in the database represented one promotional item and included the codes assigned in NVivo as well as other relevant information about the item (reference Data Dictionaries in Appendices). Last, the database was imported into SPSS statistical database format for further analysis using quantitative statistical methods. The quantitative analysis of the data is described in detail in the Analysis section of this report. .

Data Sources

Source: Manufacturer product brochures / Web pages

Eight databases provided the basis for selection of siding manufacturers. Data sources included:

1) Hanley-Wood's on-line building products data base eBuild;
2) North American Wholesale Lumber Association (NAWLA) member list;
3) The Western Red Cedar Association member list;
4) The Brick Industry Association member list;
5), The Vinyl Siding Institute, a subdivision of the American Plastics Society member list;
6) The Stucco Manufacturers Association member list;
7) The One-Coat Stucco Manufacturers Association member list;
8) The U.S. Steel Manufacturers Association member list.

APPENDIX A - LIST of MANUFACTURERS and BRANDS STUDIED contains a complete list of siding manufacturers and brands included in this study.

Siding manufacturers found in any of the eight database sources were researched on the World Wide Web (WWW). Smaller producers without Web sites were not included in this portion of the study (but may have been included in the magazine advertisement segment of the study). Data items were collected from 92 siding manufacturers and were classified into 8 material categories. *Table 7 - Siding manufacturers by material category* shows the number of manufacturers analyzed for each siding material category with the estimated North American manufacturer population for each. If a Web site or product brochure could be identified for a manufacturer, the manufacturer was included in this portion of the study.

Table 7 - Siding manufacturers by material category

Siding category	#manufacturers identified	#manufacturers included	#brands included in this study
Wood Composite	5	5	6
Solid Wood	600 (est.)	31	31
Vinyl	19	19	72
Aluminum	4	4	4
Stucco	39	7	7
Brick	43	31	32
Fiber Cement	4	3	4
Steel	25	8	9
Totals	**734(est.)**	**108**[8]	**165**

The siding industry consists of approximately 730 manufacturers, most of which are medium to small sized producers. This is especially true for solid wood siding producers as most large firms are vertically integrated, having their own source of raw material up to finished siding product (Williams 1982). We were able to include a higher percentage of manufacturers in the vinyl, wood composite and aluminum categories than in categories like solid wood. Solid wood has many manufacturers that are not easily identifiable or don't offer promotional brochures or product Web pages. A complete population of solid wood siding manufacturers is difficult to identify since many are small mills that may or may not produce siding products on a regular basis. For example, many millwork firms will produce siding as a value-added custom order. Typically, these small firms have little siding product promotion. We focused our data collection efforts on the largest producers which should account for a significant share of the solid wood siding market.

Source: Magazine advertisements

An earlier study identified builders as the primary decision makers for siding choices (Damery & Fisette, 2001). The builder group includes siding contractors, repair and remodeling contractors, and professional homebuilders. Do-It-Yourself (DIY) consumers do not play a significant role in the siding industry (Stalling 1988, p. 31).

The majority of siding industry advertising occurs in builder-focused magazines. Our goal was to examine magazines having the appropriate focus on residential homebuilding and remodeling contractors. We generated a list of builder-focused magazines using data

[8] Some manufacturers produce more than one type of siding, e.g., Louisiana-Pacific produces 2 wood composite siding products and 6 vinyl siding products. Therefore, the Total #manufacturers (108) appearing here is greater than the number of unique manufacturers (99) included in this study.

from BPA Worldwide[9], a third party circulation verification agency. Manufacturer advertisements were collected from the top 7 builder magazines as rated by BPA Worldwide in terms of circulation for the first quarter of 2005 as shown in Table 8 below.

Once publications with maximum builder reach were identified, we obtained the issues circulated for the first quarter of 2005. Manufacturers are typically involved in heavy product promotion early in the calendar year. An added promotional incentive for manufacturers is the 2005 International Builders Show which occurred Jan. 14-17, 2005. The Builders' Show features nearly 1,600 exhibitors showcasing their products and services, and attracts over 100,000 attendees. Some target magazines, such as *Builder*, have January issues dedicated to the International Builders Show.

Table 8 - Top 7 Builder-focused magazines ranked by circulation

Rank	Magazine	2005 Circulation*	Publisher
1	Fine Homebuilding	316,011 (46% builder)	Taunton Press
2	Builder	141,399	Hanley Wood Magazines
3	Professional Builder	127,000	Reed Business Information
4	Qualified Remodeler[10]	82,489	Cygnus Business Media
5	Remodeling	80,523	Hanley Wood Magazines
6	Journal of Light Construction	74,738	Hanley Wood Magazines
7	Professional Remodeler	63,400	Reed Business Information
*** Circulation figures obtained from BPA Worldwide, 2005**			

[9] BPA Worldwide is a global industry resource for verified audience data and media knowledge. For print business and consumer publications, BPA verifies all-paid, all-controlled, or any combination of paid and controlled circulation, reported in a single document, with each type of circulation broken out.

[10] Qualified Remodeler magazine was not included in this study because there were no siding advertisements in its 2005 first quarter issues.

A list of magazines that were reviewed, but were not included appears in Table 9 below. Magazines were selected for inclusion in this study based on circulation figures and quantity of advertising dedicated to siding.

Table 9 - Builder-focused magazines

Title/Topic/Home Page	2005 Average Circulation	Web site
Fine Homebuilding	316,011 (46% bldr)	http://www.taunton.com/finehomebuilding/
Builder	141,331	http://www.builderonline.com
Professional Builder	127,000	http://www.housingzone.com
Qualified Remodeler	82,489	http://www.qualifiedremodeler.com
Remodeling Magazine	80,523	http://www.remodeling.hw.net
Journal of Light Construction, The	74,738	http://www.jlconline.com/forms/jlc_kit/
Tools of the Trade	65,007	http://www.toolsofthetrade.net
Professional Remodeler	63,400	http://www.housingzone.com
Jobsite - Tools and Materials for the Framing & Drywall Professional	60,393	
Building Products	60,000	http://www.hanleywood.com
Residential Design & Build	50,070	http://www.dbbonline.com
Kitchen & Bath Design News	50,501	http://www.kitchenbathdesign.com
Kitchen & Bath Business	50,417	http://vnu.com
Custom Home	40,000	http://www.customhomeonline.com
CE Pro	35,025	http://www.ce-pro.com
Metal Construction News	31,903	http://www.moderntrade.com
Walls & Ceilings	31,484	http://www.wconline.com
Grading & Excavation Contractor	30,851	http://www.gradingandexcavation.com
Rural Builder	27,581	http://www.krause.com
Metal Home Digest	27,440	http://www.moderntrade.com
Window & Door	26,620	http://www.WindowandDoor.net
Builder and Developer	21,865	http://www.bdmag.com
Frame Building News	22,816	http://www.krause.com
Sales & Marketing Ideas	16,657	http://www.nahb.com/smiweb.html
Manufactured Home Merchandiser	15,546	
BIG BUILDER	12,505	

Source: Promotional attributes list

Databases of siding manufacturers and of builder-focused magazine circulations provided lists of potential sources of promotional materials. Once identified and collected, promotional materials were visually reviewed to develop a starting set of promotional attributes, the ‘theory’ about attributes promoted by siding manufacturers. To generate a starting list of product attributes, we perused magazines, media kits and Web pages in conjunction with attribute lists from earlier siding studies (Damery & Fisette, 2001; Stalling & Sinclair, 1989). A first review of collected materials included use of NVivo qualitative data analysis software to systematically code whether each of 27 attributes was mentioned in each promotional item. Frequency counts were not recorded in the first pass, just a Boolean flag recording whether an attribute was mentioned. The researcher continually compared and contrasted promotional materials and categories of attributes to define the best set of attributes. At the end of the first pass, the product attribute set was redefined to include 30 product attributes.

Table 10 contains the original list of 27 product attributes garnered from visual review of promotional materials and review of prior siding studies. Table 11 lists the final 30 siding product attributes developed from refinement of the initial list based on the initial study of promotional data.

In a second more thorough textual analysis pass, the researcher coded all occurrences of attributes in each promotional item to produce a database from which quantitative analyses could be performed.

Table 10 - Initial list of 27 product attributes

Aesthetics	Durability	Product integrity
Availability	Ease of installation	Strength
Certification/code approved	Ease of maintenance	Sound Reputation
Corrosion resistance	Full product line offered	Sun/UV resistance
Cost effective/economical	Impact resistant	Technological savvy
Customer service	Insect/decay resistance	Temperature resistance
Deadens/insulates Sound	Moisture resistance	Warranty offered
Design flexibility	Non- toxicity	Weather resistance
Dimensionally stability	Performs in extreme situations	Wind resistance

Table 11 Residential siding – refined list of 30 product attributes

Aesthetics	Ease of installation	Product integrity
Availability	Ease of maintenance	Strength
Certification/code approval	*Energy efficiency	*Quality
Corrosion resistance	*Environmentally friendly	Sound reputation
Cost effective/economical	Full product line offered	Sun/UV resistance
Customer service	Impact resistance	Technological savvy
Deadens/insulates sound	*Insect/mold resistance	Temperature resistance
Design flexibility	Moisture resistance	Warranty offered
Dimensional stability	Non-toxicity	Weather resistance
Durability	Performs in extreme situations	Wind resistance

* Attributes added or modified after first pass thru data

Data Collection

This study included two passes through both databases. In the first pass, if an attribute was mentioned at all in the product literature, Web site or magazine ad, we coded a simple Boolean yes/no for that attribute per siding promotional item. This first pass allowed us to refine the product attributes list, and provided a preliminary assessment of our databases. The second pass was more thorough. Frequency counts of attribute mentions per data item were coded. The results and discussion sections for this study are based on the second pass of the data.

All text from each promotional item was scanned and imported verbatim into NVivo. If a brochure or ad included more than one material, e.g., aluminum and vinyl, two separate records were entered and text that applied to both materials was entered for each record. When coding text, full lines of text were tagged instead of isolated key words to more adequately capture the expression of a product attribute. We identified and coded text strings by categorical codes to reflect product attributes. Examples of text strings and attached codes appear in *Table 12* below:

Table 12 - Sample text strings and attribute assignments

Text string	Attribute
"*a truly unique look that really improves the curb appeal of their home*"	aesthetics
"*It's guaranteed maintenance-free--for the life of the home.*"	ease of maintenance
" *It's solid*."	durability
"*It's stately*."	aesthetics
"*It saves energy and deadens sound*."	energy-efficiency deadens sound
"*Economical pricing*"	cost effective/economical
"*Over 30 years of building products and manufacturing innovation*"	sound reputation

Text string	Attribute
	technological savvy
“It's high tech, durable and guaranteed to last”	durability technological savvy
“Many styles available”	design flexibility
“Trim and accessories available”	full product line
“Handles extreme hot and cold cycles”	temperature resistant
“Can withstand 180 mph winds”	wind resistant
“Termite resistant”	insect & mold resistant
“Conveniently located distributors”	availability

The section in this report titled *ANALYSIS OF TOP FEATURE AND BENEFIT* Categories includes additional examples of text strings assigned to each feature.

Data Collection: Manufacturer product brochures / Web pages

Promotional data from siding manufacturer product brochures and Web sites was gathered between January 3, 2005 and February 18, 2005. January through March is show season for building products, the time period when manufacturers tend to distribute their most current product literature. Ninety-two manufacturers were first reviewed on the World Wide Web. Each brand of siding sold by a manufacturer was identified and reviewed as a separate data item. For example, Variform offers 17 different siding brands (See *APPENDIX A - LIST of MANUFACTURERS and BRANDS STUDIED*). One-hundred sixty brands of siding were included. Many manufacturers, such as Certainteed and Louisiana-Pacific Corp., offer a wide spectrum of building materials in addition to residential siding. Specific attention was paid to the siding product Web pages.

Printed siding literature was requested if offered, primarily in the form of brochures[11]. We specified builder literature materials when brochures were ordered. If product brochures were not available, manufacturer Web pages were analyzed further, specifically builder links when available. Product brochures were collected and analyzed for 73 siding brands, and Web pages were reviewed for the other 87 brands (See *Figure 10*).

Siding manufacturer’s brochures or product web pages were reviewed to classify all product benefits promoted. Each page of promotional material was reviewed and text that specifically mentioned a product feature or benefit was entered into a spreadsheet. For example, the text “product has a natural grain” was entered into a raw data spreadsheet. After all manufacturer literature was reviewed the promotional text was coded into general

[11] Some literature was received in the form of printed paper as opposed to folded brochures. All Printed Literature will hereafter be referred to as product brochures.

categories. For example, the text "product has a natural grain" was coded as *Aesthetics*. After all text was reviewed and entered in the spreadsheet, the raw data was imported into an NVivo database. *Figure 11 - Example Web page – U.S. Steel siding* shows pages from a sample Web site for U.S. Steel siding. NVivo software generated the report on the following pages which displays text strings with attribute code assignments for the U.S. Steel Web site shown in Figure 11.

* *

NVivo revision 2.0.163
Project: Side-Lit-www-Analysis- Date: 1/9/2006 - 3:20:27 PM
DOCUMENT CODING REPORT
Document: Case 136 USSteel Created: 7/27/2005 - 12:39:59 PM Modified: 7/28/2005 - 8:16:30 AM
Case 136 USSteel Nodes in Set: All Nodes

Node 1 of 30 **aesthetics**
Passage 1 of 2 Section 0, Para 3, 18 chars.
3: decorative coating

Passage 2 of 2 Section 0, Para 3, 55 chars.
3: Color consistency -- for dependable visual uniformity ·

Node 2 of 30 **availablity**
Passage 1 of 1 Section 0, Para 3, 171 chars.
3: Readily available -- productivity gains combined with new facilities in recent years have made prepainted steel sheet expeditiously available in every geographical market.

Node 3 of 30 **corrosion resistance**
Passage 1 of 1 Section 0, Para 3, 19 chars.
3: corrosion resistant

Node 4 of 30 **cost effective**
Passage 1 of 5 Section 0, Para 2, 95 chars.
2: Prepainted steel sheet is very cost effective for manufacturers of painted sheet steel products

---

Passage 2 of 5 Section 0, Para 2, 148 chars.
2: capital burden for paint facilities as well as paint-line costs associated with the preparation, handling, spraying and baking or drying

---

Passage 3 of 5 Section 0, Para 3, 49 chars.
3: Prepainted Steel Sheet protects your investment..

Passage 4 of 5 Section 0, Para 3, 35 chars.
3: for long service life at low cost ·

Passage 5 of 5 Section 0, Para 3, 181 chars.
3: Cost effective -- highly durable, easy to fabricate and apply, prepainted steel sheet contributes good economic value

Node 5 of 30 **design flexibility**
Passage 1 of 10 Section 0, Para 2, 76 chars.
2: practical approach to architectural and product design. The trend is to steel

---

Passage 2 of 10 Section 0, Para 3, 32 chars.
3: of its application versatility.

Passage 3 of 10 Section 0, Para 3, 208 chars.
3: For example, in the construction industry, its availability in an almost infinite variety of colors, profiles, and strengths, means it can satisfy the most creative and discerning of architects and designers.

Passage 4 of 10 Section 0, Para 3, 302 chars.
3: As the following pages show, it can beautify structures for all kinds of purposes: schools, churches, town halls, malls, libraries, medical centers, recreation centers, gymnasiums, laboratories, garages, farm buildings, warehouses, factories, office buildings, as well as homes and apartment buildings.

Passage 5 of 10 Section 0, Para 3, 185 chars.
3: USS Prepainted Steel Sheet is available in just about any combination of color, coating type and thickness, and metal thickness to meet any specific strength, design and decorative need

---

Passage 6 of 10 Section 0, Para 3, 19 chars.
3: Design flexibility

Passage 7 of 10 Section 0, Para 3, 80 chars.
3: multiplicity of grades and strength levels permits designing to specific needs ·

Passage 8 of 10 Section 0, Para 3, 57 chars.
3: Exciting colors -- rich tones in almost infinite variety

Passage 9 of 10 Section 0, Para 3, 94 chars.
3: Recoatability -- prepainted steel sheet can be repainted to coordinate with changes in decor ·

Passage 10 of 10 Section 0, Para 3, 132 chars.
3: Multiplicity of coating types and colors -- the paint performance can be engineered to exacting architectural needs and situations ·

Node 6 of 30 **durability**
Passage 1 of 2 Section 0, Para 3, 35 chars.
3: for long service life at low cost ·

Passage 2 of 2 Section 0, Para 3, 181 chars.
3: Cost effective -- highly durable.

Node 7 of 30 **easy to install**
Passage 1 of 5 Section 0, Para 2, 148 chars.
2: capital burden for paint facilities as well as paint-line costs associated with the preparation, handling, spraying and baking or drying

---

Passage 2 of 5 Section 0, Para 2, 53 chars.
2: The result: short manufacturing and assembly cycles;

Passage 3 of 5 Section 0, Para 3, 79 chars.
3: Light weight means easier handling, lower shipping costs, easier installation ·

Passage 4 of 5 Section 0, Para 3, 85 chars.
3: Excellent dent resistance -- steel sheet withstands impacts from wind-borne objects ·

Passage 5 of 5 Section 0, Para 3, 181 chars.
3: Cost effective -- highly durable, easy to fabricate and apply

Node 8 of 30 **environmentally friendly**
Passage 1 of 3 Section 0, Para 2, 62 chars.
2: a cleaner environment through the advanced pollution controls

---

Passage 2 of 3 Section 0, Para 3, 22 chars.
3: and the environment·

Passage 3 of 3 Section 0, Para 3, 79 chars.
3: Factory pollution control that is not economically feasible with post painting

Node 9 of 30 **product integrity**
Passage 1 of 1 Section 0, Para 3, 24 chars.
3: yields a highly uniform,

Node 10 of 30 **quality**
Passage 1 of 4 Section 0, Para 3, 22 chars.
3: uniformly high quality

Passage 2 of 4 Section 0, Para 3, 157 chars.
3: High quality -- in recent years steel quality and paint technology have both improved greatly, the synergistic effect results in a high-performance material

---

Passage 3 of 4 Section 0, Para 3, 12 chars.
3: high-quality

Passage 4 of 4 Section 0, Para 3, 181 chars.
3: Cost effective -- highly durable, easy to fabricate and apply, prepainted steel sheet contributes good economic value and high quality

Node 11 of 30 **strength**
Passage 1 of 1 Section 0, Para 3, 60 chars.
3: Light weight due to high strength-to-weight ratio of steel

* *

Our immediate goal was to determine manufacturer promotion of product attributes by tabulating the number of text entries that were manually coded into one or more of 30 attribute categories. Text was coded by highlighting appropriate text strings and clicking on the corresponding attribute code. The program tracked total attribute counts for each of the 30 categories per siding brand evaluated. A database was constructed to store the text attribute counts and additional manufacturer information and details about each text source. Data fields included manufacturer, brand, types of siding (lap, dutch lap, board and batten, shakes, beaded lap, etc.), warranty, median number of colors, prefinish options, and more.

APPENDIX B – Brochure / Web Data Dictionary describes the Web page / brochure data dictionary. Once the database was complete, it was imported into statistical software (SPSS) so descriptive statistics could be run on siding product attributes and categories.

Data Collection: Magazine advertisements

Six of the seven builder focused magazines contained siding advertisements. No siding advertisements were found in the 2005 first quarter issues of *Qualified Remodeler* magazine. In the first quarter issues of the other 6 magazines (*Builder*, *Professional Builder, Fine Homebuilding, Remodeler*, *Journal of Light Construction,* and *Professional Remodeler*), text copy from 19 siding manufacturers' advertisements for 26 different brands was scanned and entered verbatim into the NVivo qualitative coding program. A total of 90 advertisements were analyzed.

Ads for some brands were repeated in different magazines and/or different issues. Each advertisement was reviewed as a separate promotional data item for each type of siding material found in the ad. For example, Certainteed advertised *Weatherboards*, *Cedar Impressions, Monogram* and *TrueComfort* brands of siding in the same ad, so 1 data record was created for the vinyl sidings (*Cedar Impressions*, *Monogram, TrueComfort*), and 1 data record was created for *Weatherboards* fiber cement siding. The same siding advertisement for Crane's vinyl *Craneboard* siding was found in issue 1 and issue 3 of Professional Builder magazine, so two separate data records were created for each ad.

As with the Web pages and product brochure data, advertisement text was reviewed in NVivo and one of 30 attribute categories was attached to text as interpreted by the researcher. In LP's advertisement for its Norman Rockwell siding shown here, attribute codes were assigned to these text strings as follows:

**** * * * * * * * * * * * * * * * ****

the distinctive look of Normal Rockwell vinyl siding always makes a lasting impression - aesthetics

resist fading through Chromalock Technology – technological savvy, sun resistance

lifetime limited warranty – warranty

warranty with resistance against fading– sun resistance

only LP Norman Rockwell siding gives you deep rich colors that resist fading – aesthetics, sun resistance

with authentic cedar wood grain built into every panel - aesthetics

Now you can offer them a truly unique look that really improves the curb appeal of their home. - aesthetics

Rated #1 by a leading consumer magazine - reputation

Fade resistance 25 year protection – warranty, sun resistance

Premium .044 inch thick vinyl – product integrity

**** * * * * * * * * * * * * * * * ****

In addition to the frequency counts for promotional attributes, the following data was recorded: number of advertisements placed by each manufacturer, siding material category, location of the advertisement, page space allocated in inches, advertising copy space, image description, image size and 2005 ad rates for each ad. Once the database was complete we conducted descriptive statistical analyses for siding product attributes and advertisement characteristics.

RESULTS

Upon completion of textual data entry and processing, we reviewed the frequency of promotion for each of the 30 product attributes for all siding products by siding material category. Lists of the most and least promoted attributes were generated for each type of siding material. In addition, the Brochure/Web attribute data was compared to the magazine advertising attribute data (described in the next section). A Gap analysis was then conducted to compare promotional data to builder evaluation of select product attributes.

Product Brochures and Web pages

Descriptive Statistics

Promotional items from 92 manufacturers representing 160 siding brands were collected and analyzed. Each case represents a unique brand of siding since a single source of promotional material for each brand was included (brochures if available, and Web pages if no brochures). A total of 73 promotional items were from product brochures and 87 were based on 2005 Web pages when product brochures were not offered. All Web pages were reviewed in 2005. All brochures were requested in the first quarter of 2005. Brochure publication dates were primarily 2004. The 8% of cases with publication year prior to 2004 represent brochures with publication dates prior to 2004. See *Figure 12 - Brochure/Web Publication Date Statistics*.

Of the 160 brands studied, 45% were vinyl siding, followed by 19% brick/masonry, and 16% solid wood. The remaining categories (wood composite, fiber cement, stucco, aluminum, and steel) comprised the remaining 20% as depicted in ***Error! Reference source not found.***.

Physical layout and features

Average page size: 93.93 in^2

Information about the physical size of each item was recorded. Average page size was calculated in square inches. Printed brochures were measured with a standard ruler and page sizes were recorded for each item. The standard page size (8.5” x 11” or 93.5 sq in) was used for Web pages since most are designed to print onto a single sheet of standard paper. Average page size for brochures was 94.4 in^2. Most items were produced on standard 8.5” x 11” paper as noted by the mean in *Table 13* of 93.93 in^2.

Average number of pages: Brochure: 6.5 pages, Web: 4.4 pages

The average number of pages per promotional item was 5.38. Each Web page displayed was counted as one page; for example, when links to “Next” page or to other relevant promotional pages resulted in display of a different page, that page was counted as

a separate page. The mean number of pages for each brochure was 6.5 and the mean for Web pages per siding brand was 4.4.

Brochures and Web pages often advertised material other than siding, such as roofing, soffits or trim. The percentage of space allocated to siding promotion was also recorded in the database. As indicated by the mean of 96%, most brochures and Web pages were dedicated primarily to the advertised siding brand.

Table 13 - Page size and layout data (Brochure / Web)

	Mean	Range	Min	Max	Std. Deviation	Variance
Average Page Size	93.93 in^2	124.69 in^2	35.06 in^2	159.75 in^2	7.802 in^2	60.87 in^2
Average # of Pages	5.38	25	1	26	4.389	19.266
% dedicated to siding	96.11%	87.5%	12.5%	100%	15.29%	233.64%

n = 160

Prefinish and Warranties

Eighty-three percent (133 / 160) of siding brands studied offer a prefinish option, either in the form of primed material or a line of colors. Products like vinyl are prefinished by their nature and were marked accordingly. All brands of stucco, brick, fiber cement, and aluminum also offer a prefinish option. Other siding materials such as solid wood, steel and wood composites may or may not offer a prefinish option.

Table 14 - Prefinish option by siding material (Brochure / Web)

Siding Material	Prefinish Offered	Total Count	Percent
vinyl	73	73	100%
brick/masonry	29	30	97%*
solid wood	7	26	27%
steel	5	9	56%
stucco	7	7	100%
wood composite	3	6	50%
fiber cement	5	5	100%
aluminum	4	4	100%
TOTAL	**133**	**160**	**83%**

*one brand of stone siding did not have a prefinish option

Of the 133 brands that offer a prefinish option (83%), only 6.8% (9 / 133) offer a separate Finish warranty. Finish warranty is separate from a Product warranty.

Table 15 - Finish warranty (Brochure / Web)

# years Finish warranty	Frequency	Percent
none	151	94.4%
5 years	2	1.3
10	1	.6
12	2	1.3
15	1	.6
15-30	1	.6
25	1	.6
100	1	.6
Total	**160**	**100%**

Table 16 - Finish warranty by siding material (Brochure / Web)

	wood composite	solid wood	vinyl	aluminum	brick/ masonry	stucco	fiber cement	steel	Total
none	**5**	**23**	**72**	**4**	**29**	**6**	**3**	**9**	151
5 yrs	**1**	**1**							2
10						**1**			1
12							**2**		2
15		**1**							1
15-30		**1**							1
25			**1**						1
100					**1**				1
Total offering Product warranty	**1 of 6**	**3 of 26**	**1 of 73**	**0 of 4**	**1 of 30**	**1 of 7**	**2 of 5**	**0 of 9**	**160**

n=160

Although most siding manufacturers do not promote a Finish warranty, over half (59%, 94/160) offer a Product warranty, ranging from 5 years to lifetime. *Reference Figure 14 - Brochure/Web Product Warranty (years).*

Ninety-five percent (69 / 73) of all vinyl manufacturers market a product warranty, and 85% (62 / 73) of all vinyl manufacturers advertise a lifetime warranty. One-hundred percent of aluminum and fiber cement brands studied offer product warranties, as depicted in the table below. Only 3% (1/30) of brick/masonry manufacturers promote a product warranty, perhaps due to the nature of brick and stone material and its resistance to wear. Only 13% of solid wood siding manufacturers advertise a product warranty.

Table 17 - Product warranty by siding material (Brochure / Web)

	Wood composite	Solid wood	Vinyl	Aluminum	Brick/ masonry	Stucco	Fiber cement	Steel	Total
none	1	20	4	2	29	6		4	66
5 yrs		1							1
10						1			1
15		1							1
15-30		1							1
20								2	2
20-50		1							1
25	1		5				1		7
30	4	2					1	1	8
50			1				3		4
75			1						1
100					1				1
life			62	2				2	66
Total offering Finish warranty	5 of 6	6 of 26	69 of 73	2 of 2	1 of 30	1 of 7	5 of 5	5 of 9	160

Siding styles and colors

Siding products were also categorized by physical profile of form as depicted in the tables below. Examples of common product forms are standard lap, Dutch lap, shake, decorative shake, panel, board & batten and stucco. The average number of product types per brand displayed in each promotional item was 2.69 product types.

The most frequently offered style of siding (70%) was 'wood grain', a style that imitates the look of real wood. Sixty-one percent of siding brands offer traditional lap siding, followed by Dutch lap (45%).

Table 18 - Siding styles offered

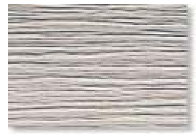
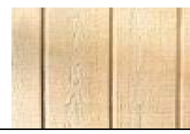
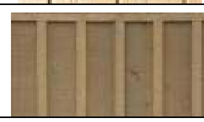
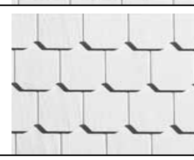
Siding style offered		Count (n=160)	Percent
Wood grain		112	70%
Lap siding		97	61%
Dutch lap		72	45%
Panel		46	29%
Board & batten		40	25%
Shakes		37	23%
Decorative shakes		31	19%
Beaded lap		30	19%
Stucco surface offered		12	8%

Table 19 below depicts the product form types promoted by each category of siding material.

Table 19 - Siding styles offered by siding material category

	Total	Lap	Wood grain	Dutch lap	Beaded lap	Board & batten	Shakes	Decorative shakes	Panel	Stucco surface
vinyl	73	62	70	59	24	14	26	20	18	-
brick/masonry	30	-	-	-	-	-	-	-	-	-
solid wood	26	21	26	4	2	15	6	7	10	-
steel	9	1	1	1	-	1	-	-	8	-
stucco	7	-	-	-	-	-	-	-	-	7
wood composite	6	4	6	3	3	5	1	1	6	2
fiber cement	5	5	5	1	1	3	4	3	4	3
aluminum	4	4	4	4	-	2	-	-	-	-
Total	**160**	**97**	**112**	**72**	**30**	**40**	**37**	**31**	**46**	**12**

One-hundred twenty-three siding brands offered color choices (77%), ranging from a choice of 4 colors up to 222 colors. Brick/masonry siding brands offered the highest average number of colors; six of the 30 brick/masonry brands offered from 105 to 222 colors.

Table 20 - Average number of colors offered

Siding material	Mean	Minimum	Maximum	n
brick/masonry	52	8	222	28
stucco	25	15	30	6
steel	14	11	19	5
vinyl	14	5	29	73
aluminum	10	8	14	4
fiber cement	8	1	19	5
solid wood	6	4	7	2
wood composite	4	1	14	4
All Siding	**22**	**1**	**222**	**127***

*33 brands did not promote number of colors

Siding Promotional Attribute Rankings

The heart of this study is the analysis of promotional attributes for types of siding material. This section reports the frequencies of mentions of 30 different promotional attributes found in product brochures or Web pages. Frequency of mentions was weighted for comparison with frequencies in magazine advertisements which are primarily one page

or less. Weighted frequency of mentions for siding attributes in product brochures or Web pages was calculated for each brand of siding as follows:

(Attribute count total) / (NbrPages * %dedicatedToSiding)

For example, for one brand, Alcoa Vinyl Siding, the Aesthetics attribute was found 29 times in a 26 page brochure. Eighty-seven percent of the brochure was dedicated to siding. The Aesthetics frequency per page (FPP) was calculated to be 1.275 mentions/page:

Aesthetics attribute count = 29
Nbr brochure pages = 26
Pct dedicated to siding = 87.5%

Weighted, Aesthetics frequency per page = 29 / (26 * .875) = 1.275

For each brand of siding, a weighted (per/page) count for each of the 30 attributes was calculated. The weighted calculations, as well as total mentions, are included in this section of the report. The most frequently promoted features in product brochures (or Web pages) were:

Aesthetics
Design Flexibility
Quality
Durability
Warranty

For all siding materials, the most frequently promoted attribute was ***Aesthetics***, mentioned in 143 of 160 cases (89%), on average 1.34 times per page, for a total of 984 occurrences. ***Design Flexibility*** was also mentioned in 143 of 160 cases for a total of 717 occurrences and a mean of 1.11 mentions per page. ***Quality*** was mentioned in 69% of all cases (110 of 160), .56 times per page, followed by ***Durability*** which was referenced in 103 of 160 cases (64%). Least mentioned features were ***Sound deadening*** capability and ***Non-toxicity***.

All Siding (Brochures / Web)

n = 160

	Attribute	# Cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 160 cases	Mean Frequency Per Case (All Pages)	Mean Frequency Per Page (FPP)*	Maximum #mentions in 1 case
1.	Aesthetics	143	89.4%	984	6.15	1.34	29
2.	Design flexibility	143	89.4%	717	4.48	1.11	23
3.	Quality	110	68.8%	350	2.19	.56	13
4.	Durability	103	64.4%	235	1.47	.39	7
5.	Warranty	98	61.3%	356	2.32	.41	23
6.	Easy to maintain	92	57.5%	279	1.74	.34	12
7.	Company/prod reputation	91	56.9%	256	1.60	.41	19
8.	Cost effectiveness	91	56.9%	286	1.79	.39	12
9.	Technologically savvy	86	53.8%	235	1.47	.34	12
10.	Strength	82	46.3%	249	1.56	.33	15
11.	Easy to install	74	46.3%	233	1.46	.33	12
12.	Weather resistant	74	37.50%	184	1.15	.23	11
13.	Full product line offered	68	36.88%	132	.82	.20	10
14.	Product integrity	67	42.5%	130	.81	.28	9
15.	Wind resistant	60	41.9%	145	.91	.24	8
16.	Code approval/certification	59	46.25%	265	1.66	.31	42
17.	Sun/UV/fade resistant	49	26.88%	113	.71	.13	11
18.	Dimensional stability	47	30.63%	99	.62	.18	7
19.	Moisture resistant	45	28.13%	94	.59	.15	7
20.	Insect/mold resistant	44	27.50%	91	.57	.15	10
21.	Customer service	43	29.38%	119	.74	.18	8
22.	Impact resistant	42	21.88%	75	.47	.09	9
23.	Performs in extreme cond.	35	26.25%	73	.46	.13	6
24.	Temperature resistant	35	15.63%	58	.36	.08	5
25.	Availability	27	15.63%	35	.22	.05	3
26.	Energy efficient	25	21.88%	78	.49	.12	21
27.	Environmentally friendly	25	16.88%	59	.37	.08	16
28.	Corrosion resistance	14	8.75%	24	.15	.04	6
29.	Deadens sound	8	5.00%	14	.09	.02	3
30.	Non-toxic	3	1.88%	3	.02	.01	1
	Total			**5971**			

Table 21 – Descending attribute frequencies, All siding, Product brochures / Web pages

*FPP = (Attribute count total) / (NbrPages * %dedicatedToSiding)
Mean FPP = $(\sum FPP) / n$
for n=160 cases

Top 5 Attributes promoted by type of siding material

Table 22 - Top Attributes by type of siding material in Brochures (or Web pages)

Wood Composite	**Solid Wood**	**Fiber Cement**	**Brick/Masonry**
Aesthetics Easy to Install Design Flexibility Warranty Cost Effectiveness Dimensional Stability	Aesthetics Design Flexibility Quality Cost Effectiveness Dimensional Stability	Design Flexibility Aesthetics Warranty Durability Insect/mold resistant	Design Flexibility Aesthetics Reputation Quality Technological Savvy

Vinyl	**Steel**	**Aluminum**	**Stucco**
Aesthetics Design Flexibility Warranty Easy to Maintain Durability Strength	Aesthetics Design Flexibility Quality Strength Code Approval	Design Flexibility Quality Reputation Aesthetics Durability	Design Flexibility Aesthetics Reputation Quality Product Integrity

Wood Composite (Brochures / Web) **n = 6**

Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 6 of 160 cases	Mean Frequency Per Case (All WC Pages)	Mean Frequency Per Page (FPP)	Median
Aesthetics	6	100%	50	8.33	.92	8
Easy to install	6	100%	42	7.00	.88	7
Design flexibility	6	100%	33	5.50	.65	4.5
Warranty	5	83.3%	46	7.67	.94	4.5
Cost effectiveness	5	83.3%	21	3.50	.46	4
Dimensional stability	5	83.3%	16	2.67	.36	2

Solid Wood (Brochures / Web) **n = 26**

Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 26 of 160 cases	Mean Frequency Per Case (All Wood Pages)	Mean Frequency Per Page (FPP)	Median
Aesthetics	19	73.1%	113	4.35	1.50	3
Design flexibility	19	73.1%	73	2.81	1.15	1.5
Quality	18	69.2%	44	1.69	.77	1
Cost effectiveness	18	69.2%	41	1.58	.73	1
Dimensional stability	16	61.5%	40	1.54	.75	1

Vinyl[12] (Brochures / Web) n = 73

Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 73 of 160 cases	Mean Freq Per Case (All Vinyl Pages)	Mean Frequency Per Page (FPP)	Median
Aesthetics	71	97.4%	640	8.77	1.67	6
Design flexibility	70	0.00%	385	5.27	1.14	4
Warranty	70	95.9%	220	3.22	.59	2
Easy to maintain	60	82.2%	211	2.89	.54	2
Durability	56	76.7%	127	1.74	.37	1
Strength	55	75.3%	187	2.56	.47	2

Aluminum (Brochures / Web) n = 4

Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 4 of 160 cases	Mean Freq Per Case (All Alum Pages)	Mean Frequency Per Page (FPP)	Median
Design flexibility	4	100%	19	4.75	1.75	5.0
Quality	4	100%	10	2.50	.76	2.5
Company/prod. reputation	4	100%	6	1.50	.56	1.5
Aesthetics	3	75%	17	4.25	1.60	4.5
Durability	3	75%	7	1.75	.44	1.5

Brick/Masonry (Brochures / Web) n = 30

Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 30 of 160 cases	Mean Freq Per Case (All Brick Pages)	Mean Frequency Per Page (FPP)	Median
Design flexibility	25	0.00%	104	3.47	.95	3
Aesthetics	24	0.00%	81	2.70	.70	2
Company/prod. reputation	24	0.00%	72	2.40	.81	2
Quality	23	0.00%	75	2.50	.85	2
Technologically savvy	17	0.00%	46	1.53	.48	1

[12] Nailite, Tapco (Foundry), and Certainteed molded polypropylene products are classified in this siding study as vinyl.

Stucco **(Brochures / Web)** **n = 7**

Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 7 of 160 cases	Mean Freq Per Case (All Stucco Pages)	Mean Frequency Per Page (FPP)	Median
Design flexibility	6	85.7%	35	5.0	.92	3
Aesthetics	6	85.7%	15	2.14	.30	2
Company/product reputation	6	85.7%	10	1.43	.33	2
Quality	5	71.4%	27	3.86	.77	3
Product Integrity	5	71.4%	6	.86	.16	1

Fiber Cement **(Brochures / Web)** **n = 5**

Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 5 of 160 cases	Mean Freq Per Case (All FC Pages)	Mean Frequency Per Page (FPP)	Median
Design flexibility	5	100%	27	5.40	.67	3
Aesthetics	5	100%	24	4.80	.73	5
Warranty	4	80%	16	3.20	.58	4
Durability	4	80%	11	2.20	.45	2
Insect/mold resistant	4	80%	9	1.80	.39	2

Steel **(Brochures / Web)** **n = 9**

Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 9 of 160 cases	Mean Freq Per Case (All Steel Pages)	Mean Frequency Per Page (FPP)	Median
Aesthetics	9	100%	44	4.89	1.61	3
Design flexibility	8	88.9%	41	4.56	1.62	3
Quality	7	77.8%	16	1.78	.67	2
Strength	6	66.7%	21	2.33	1.04	1
Code approval/certification	6	66.7%	12	1.33	.46	1

Reference APPENDIX D – Ranked Attributes by Siding Material, Brochures / Web for tables of all 30 ranked attribute frequencies per type of siding material.

Magazine advertisements

Descriptive Statistics

Ninety magazine advertisements were analyzed for 19 manufacturers representing 26 brands of siding. The 90 advertisements were collected from 6 widely circulated building trade magazines as depicted below. All advertisements were located in magazine issues from January thru March of 2005.

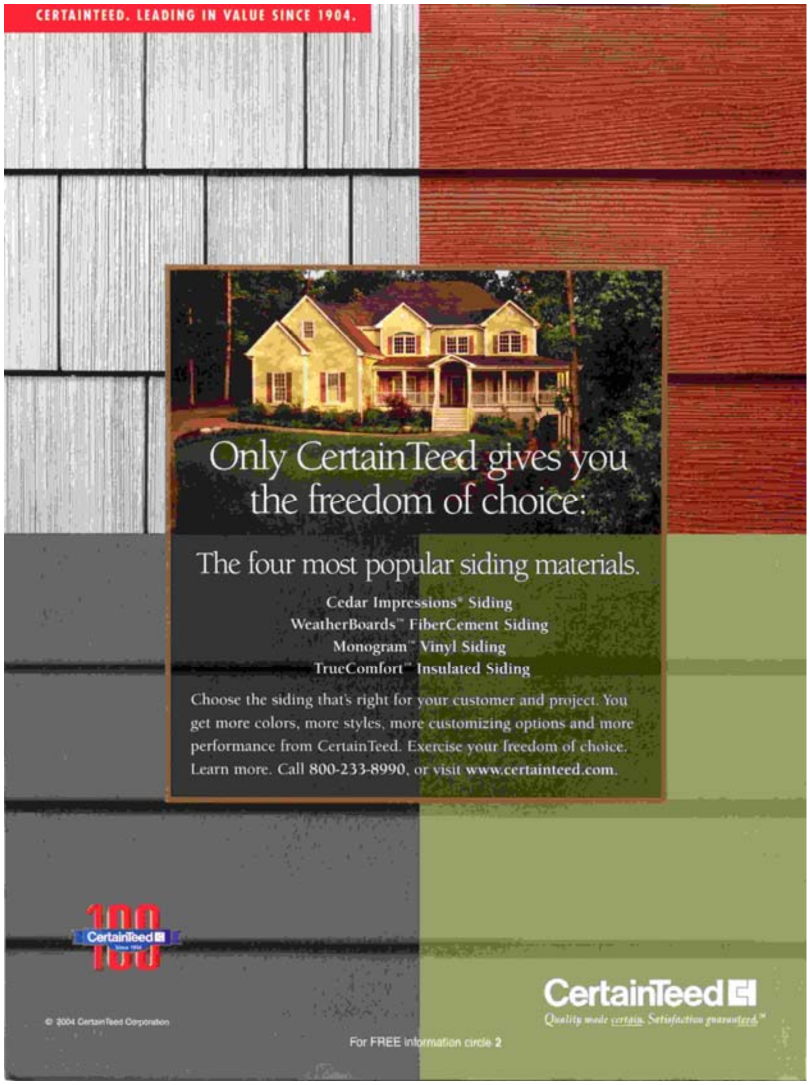
Magazine sources by siding material

Table 23 - Siding material types per Magazine

Magazine	Wood composite	solid wood	vinyl	brick/ masonry	fiber cement	Total
Builder	1		10	6	3	20
Fine Homebuilding		18				18
Journal of Light Construction		4	10		2	16
Remodeling			11		3	15
Professional Builder	1		7	4	2	14
Professional Remodeler			5		2	7
Total	**2**	**22**	**44**	**10**	**12**	**90**

As with the Brochure / Web analysis, the majority of siding advertisements (50%) were for vinyl siding. Solid wood siding (24%) was heavily advertised in *Fine Homebuilding* magazine (18 of 22 solid wood ads). See *Figure 15 – Magazine Ads, Percentages by Siding Material.* No advertisements were found for stucco, aluminum or steel siding in the builder focused magazines targeted by this study. We speculate that aluminum and steel siding advertisements may target commercial builders instead of the residential home builders and remodelers targeted by magazines used in this study.

The 19 manufacturers and the 26 brands of siding advertised are listed in Table 24 below. A total of 35 different ads were analyzed. The magazine ad database included duplicate advertisements found in different magazines or different issues of the same magazine. Those duplicates are noted in Table 24 below. In one case, multiple brands of siding for the same manufacturer were advertised in a single ad. Multiple brands of the same siding material were entered as 1 data record. For example, this Certainteed ad markets 4 brands of Certainteed siding: 3 vinyl, 1 fiber cement.



For each occurrence of the ad, 2 data records were entered: a) Weatherboards (fiber cement) and b) Monogram & TrueComfort & Cedar Impressions (vinyl).

Table 24 – Magazine Advertisements: Manufacturers and Brands

Manufacturer name	Brand Advertised	Ad Text Duplication	Brand Subtotal	Manufacturer Total
Certainteed	*Cedar Impressions, Monogram, TrueComfort, Weatherboards*	8 duplicates entered 2x each ad: a) vinyl b) fiber cement	16	4 ads, 29 occurrences
	Cedar Impressions	5 duplicates	5	
	Monogram	5 duplicates	5	
	Weatherboards	3 duplicates	3	
Royal Group Technologies	*Royal Duraplank*	3 duplicates,	4	4 ads,

Manufacturer name	**Brand Advertised**	**Ad Text Duplication**	**Brand Subtotal**	**Manufacturer Total**
		1 unique		
	Royal Group - general	2 foldouts(duplicate) 7 duplicates	9	13 occurrences
Louisiana-Pacific	*LP Maxim*		1	5 ads, 9 occurrences
	LP Smartside	2 duplicate ads	2	
	Norman Rockwell	1 unique ad 2 duplicate ads 3 duplicate ads (text in all 6 ads is nearly identical)	6	
Boral Brick	*Boral*		1	2 ads, 6 occurrences
	PastelCote	5 duplicate ads	5	
Michigan Prestain	*Michigan Prestain*	3 duplicates (vinyl) 2 duplicates (vinyl) 1 unique (fiber cement)	6	3 ads, 6 occurrences
Crane	*Craneboard*	3 duplicates 1 unique	4	2 ads, 4 occurrences
Maibec	*Maibec*	3 duplicates 1 unique	4	2 ads, 4 occurrences
Bear Creek Lumber	*Bear Creek Lumber*	2 duplicates 1 unique	3	2 ads, 3 occurrences
McGee Lumber	*McGee Lumber*	3 duplicates	3	1 ad, 3 occurrences
Granville Manufacturing Company	*Granville*	2 duplicates	2	1 ad, 2 occurrences
Hanson Brick	*Hanson*	2 duplicates	2	1 ad, 2 occurrences
Ward Clapboard Mill	*Ward Clapboard*	2 duplicates	2	1 ad, 2 occurrences
Architectural Products by Outwater	*Architectural Products by Outwater*		1	1
California Redwood Association	*California Redwood*		1	1
Eldorado Stone	*Eldorado*		1	1
James Hardie	*James Hardie*		1	1
Owens Corning	*Owens Corning*		1	1
Tapco-The foundry	*The Foundry*		1	1
Western Red Cedar Association	*Western Red Cedar Association*		1	1
19 Manufacturers	**26 Brands**	**35 different ads**		**90 occurrences**

Physical layout and features

Information about the physical layout and location of the advertisements was recorded in the siding database. The majority of the ads were positioned vertically (80/90, 89%); only 11% were positioned horizontally on the page. One advertisement was found as a foldout back cover of a magazine[13]; the other 89 ads were located inside the magazine. No siding ads were located on other strategic locations, such as on the front cover or immediately inside the front or back covers.

Ninety-six percent of ads included a graphic (86 / 90). Forty-two percent of ads (38 / 90) included multiple products in the ad, e.g., siding, trim, flooring, or roofing. As with the Brochure / Web database, the percentage of the ad devoted to siding was measured and stored.

Royal Group Technologies ran 2 identical vinyl group product advertisements as foldout inserts on heavier than normal paper. Only 6.25% (1 of 16 panels) was specific to vinyl siding while the rest of the foldout advertised other Royal vinyl products (decking, millwork, door and window profiles, vents, etc.). Owens Corning ran a 3-page foldout ad in the back of *Builder* magazine, entirely dedicated to its cultured stone veneer siding product. Other than these 3 ads, no other manufacturer advertised on non-standard magazine pages. Twenty ads were in special product sections, such as a section titled 'Builder Mart' or as mini ads toward the back of the magazines.

Table 25 - Ad type (special section, insert, weight, foldout) By Siding material

	Is ad included in a special section?	Is ad an insert?	Is weight of ad paper heavier than magazine page?	Does ad fold out?
wood composite				
solid wood	4			
vinyl[14]	15	2	2	2
brick/masonry	1		1	1
fiber cement				
Total	**20**	**2** (Royal)	**3** (Royal & Owens)	**3** (Royal & Owens)

Information about the size of each advertisement was recorded. Ad size was calculated in square inches, measured with a standard ruler. Number of pages was not recorded for advertisements, but total square inches reflects use of multiple pages. The mean physical size for each ad was 87.97 inches^2.

Seventy percent of the 90 ads studied (63 of 90) were for full page ads. Seven of 90 advertisements were larger than average page size – 3 were foldouts, and 4 were facing pages where one page displayed a graphic and the other included text. Twenty advertisements were for less than 30% of average page size. Other than the ads for solid wood which were generally not

[13] *Builder* magazine, volume 28, issue 3, 2005, contained a foldout back cover ad for Owens Corning stone siding.

[14] Ten of the ads for vinyl siding were foldout inserts on heavy duty paper. Those ten cases were also coded as in a special section. The ads were in 3 different magazines, and in different issues, but all ten were for the same manufacturer (Royal Group Technologies).

full page ads, most siding ads were full page ads. As expected and depicted in *Figure 16 - Magazine ad sizes and rates*, Ad sizes correlated with advertising rates.

Solid wood advertisements averaged about one-third of a page (34.30 in^2), while the size of ads for other types of siding averaged about a standard page size as reflected below.

Table 26 - Ad size statistics, in square inches

	Mean	Median	Minimum	Maximum	n
wood composite	85.44	85.44	78.75	92.13	2
solid wood	34.30	23.41	7.80	93.63	22
vinyl	108.19	82.69	18.08	630.00	44
brick/masonry	105.20	92.13	78.75	276.38	10
fiber cement	98.33	82.69	78.75	184.25	12
All Siding	**89.97in^2**	**82.20in^2**	**7.80 in^2**	**630.00 in^2**	**90**

Table 27 - Layout, percent of page

	Mean	Median	Minimum	Maximum	n
wood composite	100	100	100	100	2
solid wood	37.81	25	0.08	100	22
vinyl	92.55	100	22.20	100	44
brick/masonry	100	100	100	100	10
fiber cement	100	100	100	100	12
All Siding	**81.16%**	**100%**	**.08%**	**100%**	**90**

Advertising Rates

All advertising rates were found in magazine media kits. The average cost of siding ads studied was $16,010, ranging from $1,135 for a 7.8 in^2 ad to $137,440 for a 630 in^2 foldout ad.

Table 28 - Rate as of 2005 rate card for ad

	Mean	Median	Minimum	Maximum	n
wood composite	$15,755	$15,755	$14,330	$17,180	2
solid wood	6,347	5,043	1,135	21,220	22
vinyl	19770	15,250	1,760	137,440	44
brick/masonry	19,927	17,180	14,330	56,045	10
fiber cement	16,714	15,250	9,430	34,360	12
All Siding	**$16,010**	**$15,250**	**$1,135**	**$137,440**	**90**

Siding Promotional Attribute Rankings

This section reports the frequencies of mentions of 25 different promotional attributes[15] found in residential siding magazine advertisements targeted at home builders and remodelers. Frequency of mentions were not weighted for magazine advertisements since most advertisements appear on 1 page (83 of 90, 92%), or the facing page(s) are graphics only or for non-siding products.

Most frequently promoted features were:

Design Flexibility
Company/product reputation
Aesthetics
Quality
Full Product Line

The most frequently promoted attribute was *Design Flexibility*, mentioned in 67 of 90 cases (74%), on average 2.42 times per promotional item, for a total of 218 occurrences. *Company/product reputation* was mentioned in nearly as many cases, 58 of 90 (64%), for a total of 157 occurrences and a mean of 1.74 mentions. *Aesthetics* was promoted on average 1.28 times in 53 of 90 cases, 59%, followed by *Quality* and *Full product line.*

Five attributes were not promoted in any magazine advertisements:
Corrosion resistance, *Dimensional Stability*, *Environmental friendliness*, *Non-toxicity* and *Temperature resistance*

[15] Five attributes were not promoted in any of the magazine advertisements studied; therefore, only 25 attributes were analyzed in conjunction with the magazine ad database.

All Siding (Magazine Ads)

n = 90 cases

	Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 90 cases	Mean Frequency Per Case	Median
1	Design Flexibility	67	74.4%	218	2.42	1
2	Company/prod. reputation	58	64.4%	157	1.74	1
3	Aesthetics	53	58.9%	115	1.28	1
4	Quality	52	57.8%	64	.71	1
5	Full product line offered	46	51.1%	62	.69	1
6	Warranty offered	42	46.7%	57	.63	0
7	Cost effectiveness	41	45.6%	46	.51	0
8	Easy to maintain	30	33.3%	30	.33	0
9	Easy to install	20	22.2%	32	.36	0
10	Technologically savvy	19	21.1%	33	.37	0
11	Product integrity	15	16.7%	24	.27	0
12	Customer service	15	16.7%	17	.19	0
13	Sun resistant	11	12.2%	23	.26	0
14	Durability	10	11.1%	13	.14	0
15	Strength	9	10.0%	19	.21	0
16	Moisture resistant	9	10.0%	9	.10	0
17	Energy efficient	7	7.8%	10	.11	0
18	Impact resistant	6	6.7%	10	.11	0
19	Code approval / certification	6	6.7%	6	.07	0
20	Weather resistant	5	5.6%	5	.06	0
21	Performs in extreme cond.	4	4.4%	6	.07	0
22	Availability	4	4.4%	5	.06	0
23	Wind resistant	3	3.3%	6	.07	0
24	Deadens sounds	3	3.3%	3	.03	0
25	Insect resistant	1	1.1%	1	.01	0
	Corrosion resistance					
	Dimensional stability					
	Environmentally friendly					
	Non-toxic					
	Temperature resistant					
	TOTAL			**971**		

Top 5 Attributes promoted by type of siding material

Table 29 - Top Attributes by type of siding material in Magazine Ads

Wood Composite	Solid Wood	Vinyl	Brick/Masonry	Fiber Cement
Aesthetics	Design Flexibility	Quality	Design Flexibility	Reputation
Easy to Install	Aesthetics	Reputation	Aesthetics	Quality
Durability	Reputation	Design Flexibility	Cost Effectiveness	Cost Effectiveness
Cost Effectiveness	Cost Effectiveness	Full Product Line	Easy to Install	Full Product Line
Design Flexibility	Warranty	Aesthetics	Easy to Maintain	Design Flexibility
Warranty		Warranty		

Wood Composite (Magazine Ads) **n = 2 cases**

Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 90 cases	Mean Frequency Per Case	Median
Aesthetics	2	100%	8	4	4
Easy to install	2	100%	6	3	3
Durability	2	100%	4	2	2
Cost effectiveness	2	100%	2	1	1
Design Flexibility	2	100%	2	1	1
Warranty offered	2	100%	2	1	1

Solid Wood (Magazine Ads) **n = 22 cases**

Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 90 cases	Mean Frequency Per Case	Median
Design Flexibility	15	68.2%	18	.82	1
Aesthetics	13	59.1%	14	.64	1
Company/prod. reputation	10	45.5%	11	.50	0
Cost effectiveness	8	36.4%	11	.50	0
Warranty offered	7	31.8%	8	.36	0

Vinyl (Magazine Ads) **n = 44 cases**

Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 90 cases	Mean Frequency Per Case	Median
Quality	35	79.5%	42	.95	1
Company/prod. reputation	34	77.3%	108	2.45	3
Design Flexibility	31	70.5 %	105	2.39	1.5
Full product line offered	28	63.6%	42	.95	1
Aesthetics	24	54.5%	56	1.27	1
Warranty offered	23	52.3%	37	.84	1

Brick/Masonry (Magazine Ads) **n = 10 cases**

Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 90 cases	Mean Frequency Per Case	Median
Design Flexibility	10	100%	42	4.20	4
Aesthetics	10	100%	27	2.70	2
Cost effectiveness	10	100%	2	.20	0
Easy to install	7	70%	7	.70	1
Easy to maintain	7	70%	7	.70	1

Fiber Cement (Magazine Ads) **n = 12 cases**

Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 90 cases	Mean Frequency Per Case	Median
Company/product reputation	12	100%	36	3.00	3
Quality	12	100%	12	1.00	1
Cost effectiveness	11	91.6%	11	.92	1
Full product line offered	11	91.6%	11	.92	1
Design Flexibility	9	75.0%	51	4.25	6

Reference APPENDIX D – Ranked Attributes by Siding Material, Brochures / Web for tables of all 30 ranked attribute frequencies per type of siding material.

Combined: Magazine Advertisements + Brochures / Web

Descriptive Statistics

Two-hundred fifty promotional cases representing 90 magazine advertisements, 73 product brochures and 87 Web pages were analyzed. The 250 cases contain 99 different manufacturers representing 165 unique brands of siding (Appendix A lists all manufacturers and brands included in this study). The 90 advertisements were collected from 6 widely circulated building trade magazine issues from January thru March of 2005. The 73 product brochures were requested in first quarter of 2005 and the 87 Web pages represent siding brands for which product brochures were not available in early 2005. Twelve of the manufacturers were included in both the Advertisement database and the Brochure / Web database; those manufacturers will have multiple cases in the combined database described here, representing their magazine advertisements as well as their product brochures or Web pages.

Siding Promotional Attribute Rankings

Most frequently promoted features were:

Design Flexibility
Aesthetics
Quality
Company/product reputation
Warranty

The most frequently promoted attribute was *Design Flexibility*, mentioned in 210 of 250 cases (84%), on average 1.58 times per page, per promotional item, for a total of 395 occurrences. *Aesthetics* was mentioned in 196 cases (78.4%) and was promoted on average 1.32 times per page.

All Siding (Combined)

n = 250 cases

	Attribute	#f cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 250 cases	Mean Frequency Per Case	Mean Frequency Per Page (FPP)*
1	Design Flexibility	210	84.0%	935	3.74	1.58
2	Aesthetics	196	78.4%	1099	4.40	1.32
3	Quality	162	64.8%	414	1.66	.61
4	Company/prod. reputation	149	59.6%	413	1.65	.89
5	Warranty offered	140	56.0%	428	1.71	.53
6	Cost effectiveness	132	52.8%	332	1.33	.43
7	Easy to maintain	122	48.8%	309	1.24	.34
8	Full product line offered	114	45.6%	194	.78	.37
9	Durability	113	45.2%	248	.99	.30
10	Technologically savvy	105	42.0%	268	1.07	.35
11	Easy to install	94	37.6%	265	1.06	.34
12	Strength	91	36.4%	268	1.07	.28
13	Product integrity	82	32.8%	154	.62	.28
14	Weather resistant	79	31.6%	189	.76	.17
15	Code approval / certification	65	26.0%	271	1.08	.23
16	Wind resistant	63	25.2%	151	.60	.17
17	Sun resistant	60	24.0%	136	.54	.18
18	Customer service	58	23.2%	136	.54	.18
19	Moisture resistant	54	21.6%	103	.41	.13
20	Impact resistant	48	19.2%	85	.34	.10
21	Dimensional stability	47	18.8%	99	.40	.12
22	Insect resistant	45	18.4%	92	.37	.10
23	Performs in extreme cond.	39	15.6%	79	.32	.10
24	Temperature resistant	35	14.0%	58	.23	.05
25	Energy efficient	32	12.8%	88	.35	.12
26	Availability	31	12.4%	40	.16	.05
27	Environmentally friendly	25	10.0%	59	.24	.05
28	Corrosion resistance	14	5.6%	24	.10	.03
29	Deadens sounds	11	4.4%	17	.07	.03
30	Non-toxic	3	1.2%	3	.01	.01
	TOTAL			**6957**		

90 Magazine Ads, 73 Product Brochures, 87 Web Pages

*FPP = (Attribute count total) / (NbrPages * %dedicatedToSiding)
Mean FPP = $(\sum \text{FPP}) / n$
for n=250 cases

Top 5 Attributes promoted by type of siding material

Table 30 - Top Attributes by type of siding material in Combined Databases

Wood Composite	Solid Wood	Vinyl	Brick/Masonry	Fiber Cement
Aesthetics	Design Flexibility	Reputation	Design Flexibility	Reputation
Easy to Install	Aesthetics	Quality	Aesthetics	Quality
Durability	Reputation	Design Flexibility	Cost Effectiveness	Cost Effectiveness
Cost Effectiveness	Cost Effectiveness	Full Product Line	Easy to Install	Full Product Line
Design Flexibility	Warranty	Aesthetics	Easy to Maintain	Design Flexibility
Warranty				

Wood Composite (Combined Databases)

n = 8 cases
6 Ads, 2 Brochure / Web

Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 8 of 250 cases	Mean Frequency Per Case	Mean Frequency Per Page
Aesthetics	8	100%	58	7.25	1.69
Easy to install	8	100%	48	6.00	1.41
Design Flexibility	8	100%	35	4.38	.74
Warranty offered	7	87.5%	48	6.00	.95
Cost effectiveness	7	87.5%	23	2.88	.59

Solid Wood (Combined Databases)

n = 48 cases
22 Ads, 26 Brochure / Web

Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 48 of 250 cases	Mean Frequency Per Case	Mean Frequency Per Page
Design Flexibility	34	70.8%	91	1.90	1.00
Aesthetics	32	66.7%	127	2.65	1.10
Cost effectiveness	26	54.2%	52	1.08	.62
Quality	24	50.0%	52	1.08	.58
Company/prod. reputation	23	47.9%	27	.56	.40

Vinyl (Combined Databases) **n = 117 cases**
44 Ads, 73 Brochure / Web

Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 117 of 250 cases	Mean Frequency Per Case	Mean Frequency Per Page
Design Flexibility	101	86.3%	490	4.19	4.19
Aesthetics	95	81.2%	696	5.95	5.95
Warranty offered	93	79.5%	272	2.32	2.32
Quality	83	70.9%	203	1.74	1.74
Company/prod. reputation	74	63.2%	242	2.07	2.07
Easy to maintain	74	63.2%	225	1.92	1.92

Brick/Masonry (Combined Databases) **n = 40 cases**
10 Ads, 30 Brochure / Web

Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 40 of 250 cases	Mean Frequency Per Case	Mean Frequency Per Page
Design Flexibility	35	87.5%	146	3.65	1.76
Aesthetics	34	85.0%	108	2.70	1.20
Company/prod. reputation	26	65.0%	74	1.85	.66
Quality	24	60.0%	77	1.92	.69
Cost effectiveness	24	60.0%	65	1.63	.39

Fiber Cement (Combined Databases) **n = 17 cases**
12 Ads, 5 Brochure / Web

Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 17 of 250 cases	Mean Frequency Per Case	Mean Frequency Per Page
Design Flexibility	14	82.4%	78	4.59	3.00
Company/prod. reputation	13	76.5%	44	2.59	1.00
Quality	13	76.5%	18	1.06	.92
Full product line offered	13	76.5%	15	.88	.92
Cost effectiveness	12	70.6%	12	.71	4.25

Stucco, Steel and Aluminum sidings were not mentioned in Magazine Advertisements. These tables are duplicates of the tables for Brochure / Web database only.

Stucco (Combined Databases) **n = 7 cases**
0 Ads, 7 Brochure / Web

Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 7 of 250 cases	Mean Frequency Per Case	Mean Frequency Per Page
Design flexibility	6	85.7%	35	5.0	.92
Aesthetics	6	85.7%	15	2.14	.30
Company/product reputation	6	85.7%	10	1.43	.33
Quality	5	71.4%	27	3.86	.77
Product integrity	5	71.4%	6	.86	.16

Steel (Combined Databases) **n = 9 cases**
0 Ads, 9 Brochure / Web

Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 9 of 250 cases	Mean Frequency Per Case	Mean Frequency Per Page
Aesthetics	9	100%	44	4.89	1.61
Design flexibility	8	88.9%	41	4.56	1.62
Quality	7	77.8%	16	1.78	.67
Strength	6	66.7%	21	2.33	1.04
Code approval/certification	6	66.7%	12	1.33	.46

Aluminum (Combined Databases) **n = 4 cases**
0 Ads, 4 Brochure / Web

Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 4 of 250 cases	Mean Frequency Per Case	Mean Frequency Per Page
Design flexibility	4	100%	19	4.75	1.75
Quality	4	100%	10	2.50	.76
Company/prod. reputation	4	100%	6	1.50	.56
Aesthetics	3	75%	17	4.25	1.59
Durability	3	75%	7	1.75	.44

Reference APPENDIX D – Ranked Attributes by Siding Material, Brochures / Web for tables of all 30 ranked attribute frequencies per type of siding material.

Analysis of Top Feature and Benefit Categories

Thirty categories of siding product features/benefits were evaluated in this study. The top five promotional attributes, based on magazine advertisements and product brochures or Web pages, are presented in this section. The most frequently promoted attributes were *Design flexibility*, *Aesthetics*, *Quality*, *Company/product reputation* and *Warranty*. Discussion and analysis of the remaining 25 attributes can be found in *APPENDIX G – Attribute Analysis* .

Frequencies of mention were combined for the 2 databases: magazine ads and brochures/Web promotion. Brochure/Web frequencies were weighted by number of pages and percent dedicated to siding. Magazine ad frequencies were not weighted. Promotional frequency for each feature is delineated by siding material classification.

Design flexibility

Table 31 - *Design Flexibility* Analysis by Siding Material

Siding material	N	Mean Freq per Page	Median
fiber cement	17	3.20	3.00
brick/masonry	40	1.76	1.13
aluminum	4	1.75	1.20
vinyl	117	1.61	1.00
steel	9	1.62	1.50
solid wood	48	1.00	1.00
stucco	7	.92	.86
wood composite	8	.74	.85
Total	**250**	**1.58**	**1.00**

Design flexibility describes the ability of a siding material to be incorporated within numerous architectural styles, housing designs and siding layout schemes. Design flexibility was the most promoted attribute for all categories of siding materials. Manufacturer promotional texts such as "*color variety,*" "*Your home takes shape with our complete array of profiles,*" and "*style variety*" were included in the design flexibility category. By far, fiber cement siding manufacturers promote design flexibility most frequently. Fiber cement manufacturers promote variety of colors, finishes, styles, edges and textures. Wood composite siding manufacturers promoted design flexibility the least of all siding classifications, but still promote it as one of their top features (Reference *Attribute Promotion by Siding Material* section in this report.) Brick manufacturers promoted color and texture variety heavily. For example, "*Smooth bricks. Rough bricks. Bricks with a flat even color. Bricks that mix myriads of shades and hues. Rich reds. Hearty earth tones. Soft pastels. Evocative blends...*" Aluminum siding manufacturers promoted a wide variety of color offerings. Stucco producers highlighted their product's color and texture, and heavily promoted the ability to produce custom colors and textures.

Aesthetics

Table 32 - *Aesthetics* Analysis by Siding Material

Siding material	N	Mean Freq per Page	Median
wood composite	8	1.69	1.3
steel	9	1.61	1.1
aluminum	4	1.59	.9
vinyl	117	1.52	1.0
brick/masonry	40	1.20	1.0
solid wood	48	1.10	1.0
fiber cement	17	.80	.31
stucco	7	.30	.25
Total	**250**	**1.32**	**1.0**

The Aesthetics category captured all manufacturer claims of product beauty, desired looks, curb appeal or attractive exterior. Examples from manufacturer promotional literature include "*beauty,*" "*fewer seams,*" and "*wood-like appearance.*" All manufacturers strongly promote the aesthetics feature. Wood composite manufacturers promote their siding as having aesthetic appeal similar to natural wood. Aluminum and steel are sometimes considered less attractive for residential siding which could explain increased promotion of the aesthetic value of aluminum/steel siding. Stucco manufacturers promoted aesthetics the least, choosing instead to emphasize attributes unrelated to appearance, such as design flexibility, quality and code approval.

Quality

Table 33 - *Quality* Analysis by Siding Material

Siding material	N	Mean Freq per Page	Median
stucco	7	.77	.67
fiber cement	17	.77	1.00
aluminum	4	.76	.70
brick/masonry	40	.69	.47
steel	9	.67	.50
vinyl	117	.58	.50
solid wood	48	.58	.04
wood composite	8	.19	.00
Total	**250**	**.61**	**.50**

This feature captures references to quality across all facets of a manufacturer's operations from product quality to quality control in operations. Sample text strings include *"offers a combination of quality and value," "unparalleled product quality,"* and *"Quality you can count on."* Stucco, fiber cement, and aluminum siding producers promoted quality most frequently, followed closely by steel, vinyl and solid wood. Only wood composite siding manufacturers promoted quality infrequently.

Company/product reputation

Table 34 - *Reputation* Analysis by Siding Material

Siding material	N	Mean Freq per Page	Median
fiber cement	17	2.20	3.00
vinyl	117	1.13	.25
brick/masonry	40	.66	.50
aluminum	4	.56	.45
solid wood	48	.40	.00
stucco	7	.33	.17
steel	9	.20	.00
wood composite	8	.06	.00
Total	**250**	**.87**	**.24**

The category of company or product reputation was created to capture promotional references that strengthen the legitimacy of a siding manufacturer and its products. Textual references such as "*Many of the nation's most reputable home builders use…*," company history, e.g., "*Since 1891, homebuyers have trusted…*" and "*Consumer focus group testing shows that our texture looks more like painted wood than competitive vinyl sidings*," were captured in the reputation category. Fiber cement siding manufacturers promoted company reputation by far the most, more than twice per page. Vinyl manufacturers also emphasize reputation. The high count of vinyl manufacturers (117 mfr/brands in this study) suggests that vinyl manufacturers attempt to differentiate their product based on reputation. Brick manufacturer promotion emphasized company histories in the brick making business. Steel siding manufacturers did not rely on company reputation as a feature, which may be part of their overall lack of builder focused promotion.

Warranty

Table 35 - *Warranty* Analysis by Siding Material

Siding material	N	Mean Freq per Page	Median
wood composite	8	.95	.92
aluminum	4	.82	.50
vinyl	117	.69	.50
steel	9	.46	.11
fiber cement	17	.40	.00
solid wood	48	.40	.00
stucco	7	.27	.00
brick/masonry	40	.21	.00
Total	**250**	**.53**	**.25**

The warranty category captures all text that specifically mentioned product warranties which included both substrate and finish warranty text. Promotional text such as "*Lifetime Limited Transferable Warranty*" and "*lowest warranty claims in the industry*" were included in the warranty category. Wood composite siding manufacturers promoted warranty most often, possibly to counteract older (1990's and prior) Class Action lawsuits involving wood composite siding material.[16] Aluminum manufacturers also promote warranty consistently.

[16] Status of various class action lawsuits against wood composite siding manufacturers can be found at http://www.sidingsolutions.com/pages/classtat.htm. Some lawsuits are pending while others have been settled.

Attribute Promotion by Siding Material

Introduction

Text usage counts were recorded for 30 product feature categories for eight siding materials. Counts were weighted for Product brochure / Web page promotions to represent mean number of mentions per page. Means were not weighted for advertisements since most magazine advertisements were for 1 page or less[17].

As shown in Table 36 below, the top product attributes mentioned across all siding material categories were *Design flexibility*, *Aesthetics*, *Quality*, *Company product/reputation* and *Warranty*. Non-toxicity, Sound deadening capability, Corrosion resistance, Availability and Environmental friendliness were the least mentioned across all siding material categories.

Table 36 - Promotional Attribute Ranking, All Siding, combined databases

	Attribute	% of cases mentioning attribute at least once	Mean Freq Per Page (FPP)*		Attribute	% of cases mentioning attribute at least once	Mean Freq Per Page (FPP)*
1	Design Flexibility	84.0%	1.58	16	Wind resistant	25.2%	.17
2	Aesthetics	78.4%	1.32	17	Sun resistant	24.0%	.18
3	Quality	64.8%	.61	18	Customer service	23.2%	.18
4	Company/prod. reputation	59.6%	.89	19	Moisture resistant	21.6%	.13
5	Warranty offered	56.0%	.53	20	Impact resistant	19.2%	.10
6	Cost effectiveness	52.8%	.43	21	Dimensional stability	18.8%	.12
7	Easy to maintain	48.8%	.34	22	Insect resistant	18.4%	.10
8	Full product line offered	45.6%	.37	23	Performs in extreme cond	15.6%	.10
9	Durability	45.2%	.30	24	Temperature resistant	14.0%	.05
10	Technologically savvy	42.0%	.35	25	Energy efficient	12.8%	.12
11	Easy to install	37.6%	.34	26	Availability	12.4%	.05
12	Strength	36.4%	.28	27	Environmentally friendly	10.0%	.05
13	Product integrity	32.8%	.28	28	Corrosion resistance	5.6%	.03
14	Weather resistant	31.6%	.17	29	Deadens sounds	4.4%	.03
15	Code approval / certif..	26.0%	.23	30	Non-toxic	1.2%	.01

n = 250: 90 Magazine ads, 73 Brochures, 87 Web sites

Overall, siding manufacturers convey the general message to builders that their products have curb appeal, can be incorporated into a multitude of home designs, have high quality, image or status, and are backed by a reputable company and product warranty.

Attribute rankings by siding material category are displayed and discussed further in this section. Features promoted most frequently are highlighted. *Design flexibility*, the ability of a

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[17] One advertisement was a 3-page foldout ad containing large graphics. The other 6 multiple page ads were for multiple products where siding was promoted on 1 page or less.

siding material to be incorporated within numerous architectural styles, housing designs and siding layout schemes, appears at least once in 75% (188 of 250) of all promotional items. *Aesthetics* is also heavily promoted for all siding products.

In addition to *Design flexibility* and *Aesthetics*, manufacturers promote particular features within each material classification. Wood composite is the only group that does not frequently promote Quality. Solid wood, Wood composite and Steel don't promote *Company/product reputation* as frequently as other classifications.

Solid wood:	Cost effectiveness, Quality
Wood composite:	Easy to install, Warranty, Cost effectiveness
Vinyl:	Warranty, Quality, Reputation
Brick / masonry:	Reputation, Quality, Cost effectiveness
Fiber cement:	Reputation, Quality, Full product line, Cost effectiveness
Stucco:	Reputation, Quality, Product integrity
Aluminum:	Quality, Reputation
Steel:	Quality, Strength, Code approval/certification

Detailed analysis and attribute rankings for each siding material classification appear in the remainder of this section.

Solid wood

Solid wood manufacturers promoted the top features of *Design flexibility*, *Aesthetics*, *Cost effectiveness* and *Quality*. Only solid wood siding manufacturers promote *Cost effectiveness* as a prime benefit. Corrosion resistance, impact resistance and non-toxicity were never mentioned for solid wood siding. Review of the solid wood siding promotional literature reveals that manufacturers endorse the inimitable natural look of wood and argue wood's aesthetic aspects of luster, texture and color. Moreover, promotional literature includes rhetoric about 100% on-grade product, for example "…made from premium grade kiln dried SPF material." It appears that many manufacturers are trying to improve upon the image of historically lax grading standards where on-grade meant that =/- 5% of the material could be a lower grade. Finally, solid wood manufacturers argue that wood is very workable and that only simple tools are needed (Easy to install). Given that most siding is cut outside or in a well-ventilated area toxicity is not likely to be an issue.

Table 37 - Promotional Attribute Ranking, Solid wood, combined databases

	Attribute	% of cases mentioning attribute at least once	Mean Freq Per Page (FPP)*		Attribute	% of cases mentioning attribute at least once	Mean Freq Per Page (FPP)*
1	Design Flexibility	70.8%	1.00	16	Environmentally friendly	25.2%	.17
2	Aesthetics	66.7%	1.10	17	Code approval/certif..	24.0%	.18
3	Cost effectiveness	54.2%	.62	18	Insect resistant	23.2%	.18
4	Quality	50.0%	.58	19	Weather resistant	21.6%	.13
5	Company/prod. reputation	47.9%	.40	20	Strength	19.2%	.10
6	Easy to install	35.4%	.49	21	Energy efficient	18.8%	.12
7	Durability	35.4%	.43	22	Availability	18.4%	.10
8	Dimensional stability	33.3%	.41	23	Sun resistant	15.6%	.10
9	Warranty offered	29.2%	.40	24	Performs in extreme cond.	14.0%	.05
10	Customer service	29.2%	.24	25	Wind resistant	12.8%	.12
11	Easy to maintain	25.0%	.17	26	Deadens sounds	12.4%	.05
12	Full product line offered	25.0%	.25	27	Corrosion resistance	10.0%	.05
13	Moisture resistant	22.9%	.20	28	Temperature resistant	5.6%	.03
14	Product integrity	22.9%	.34	29	Impact resistant	4.4%	.03
15	Technologically savvy	22.9%	.13	30	Non-toxic	1.2%	.01

Solid wood n = 48 (22 Ads, 1 Brochure, 25 Web sites)

Wood Composites

The top five attributes promoted by wood composite siding manufacturers are *Aesthetics*, *Ease of installation*, *Design Flexib*ility, *Warranty and Cost Effectiveness* as shown below. Wood composite siding is the only material studied that frequently promotes *Ease of installation* and *Durability*. Only wood composite and aluminum siding manufacturers heavily promote manufacturer's warranty. Wood composite manufacturers emphasize that their products cut and install like wood without the defects and problems of natural wood. Manufacturers also promote *Design flexibility* and *Durability*, conceivably to expand their product's perception beyond a simple clapboard replacement product or earlier utilitarian versions of hardboard.

Wood composite is the only siding material that does not heavily promote *Quality*. The least promoted attributes are related to damage and weather resistance, energy efficiency, sound deadening capability, and availability. Resistance to elements (wind, sun, temperature, extreme conditions) was seldom, if at all, promoted for wood composite siding. Performance in extreme conditions was minimally mentioned perhaps to avoid applications where excessive exposure to the elements may accelerate product failure, for example in coastal environments. Availability was also seldom mentioned which could be a result of siding material availability being expected by builders, i.e., as a must have in order to compete. Energy efficiency and sound deadening features are not promoted at all for wood composite siding.

Table 38 - Promotional Attribute Ranking, Wood composite, combined databases

	Attribute	% of cases mentioning attribute at least once	Mean Freq Per Page (FPP)*		Attribute	% of cases mentioning attribute at least once	Mean Freq Per Page (FPP)*
1	Aesthetics	100%	1.69	16	Full product line offered	37.5%	.06
2	Easy to install	100%	1.41	17	Insect resistant	25.0%	.24
3	Design Flexibility	100%	.74	18	Code approval/certif..	25.0%	.17
4	Warranty offered	87.5%	.95	19	Company/prod. reputation	25.0%	.06
5	Cost effectiveness	87.5%	.59	20	Customer service	25.0%	.08
6	Durability	75.0%	.67	21	Availability	25.0%	.04
7	Dimensional stability	62.5%	.27	22	Temperature resistant	25.0%	.04
8	Strength	50.0%	.22	23	Performs in extreme cond.	12.5%	.04
9	Easy to maintain	50.0%	.17	24	Impact resistant	12.5%	.02
10	Environmentally friendly	50.0%	.13	25	Corrosion resistance		
11	Moisture resistant	37.5%	.22	26	Deadens sounds		
12	Quality	37.5%	.19	27	Energy efficient		
13	Weather resistant	37.5%	.17	28	Non-toxic		
14	Technologically savvy	37.5%	.17	29	Sun resistant		
15	Product integrity	37.5%	.08	30	Wind resistant		

Wood composite **n = 8 (2 Ads, 4 Brochures, 2 Web sites)**

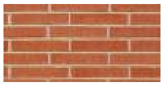
Vinyl

Vinyl siding manufacturers most often promoted *Design flexibility, Aesthetics, Warranty, Quality* and *Company/product reputation*. Vinyl manufacturers heavily promote their products' beauty and curb appeal. The promotion of product and company reputation, as well as warranty and quality, is likely a response to past product failures where old vinyl siding did not meet performance expectations (fading, cracking, sagging, etc.). Vinyl is relatively inert when used in normal service conditions, thus lack of promotion of features related to stability, extreme conditions and resistance to elements.

Table 39 - Promotional Attribute Ranking, Vinyl, combined databases

	Attribute	% of cases mentioning attribute at least once	Mean Freq Per Page (FPP)*		Attribute	% of cases mentioning attribute at least once	Mean Freq Per Page (FPP)*
1	Design Flexibility	86.3%	1.61	16	Easy to install	39.3%	.26
2	Aesthetics	81.2%	1.52	17	Impact resistant	33.3%	.19
3	Warranty offered	79.5%	.69	18	Code approval/certification	27.4%	.26
4	Quality	70.9%	.58	19	Temperature resistant	22.2%	.09
5	Company/prod. reputation	63.2%	1.13	20	Moisture resistant	18.8%	.10
6	Easy to maintain	63.2%	.45	21	Insect resistant	17.9%	.07
7	Full product line offered	61.5%	.51	22	Dimensional stability	17.1%	.04
8	Strength	53.8%	.44	23	Customer service	16.2%	.12
9	Technologically savvy	53.8%	.51	24	Performs in extreme cond.	14.5%	.05
10	Cost effectiveness	52.1%	.34	25	Energy efficient	12.0%	.15
11	Durability	50.4%	.25	26	Availability	7.7%	.01
12	Wind resistant	46.2%	.34	27	Deadens sounds	5.1%	.03
13	Weather resistant	43.6%	.24	28	Corrosion resistance	4.3%	.02
14	Product integrity	41.0%	.33	29	Environmentally friendly	2.6%	.01
15	Sun resistant	39.3%	.33	30	Non-toxic	1.7%	.00

Vinyl n = 117 (44 Ads, 54 Brochures, 19 Web sites,)



Brick/Masonry

Brick producers promoted *Design flexibility, Aesthetics, Company/product reputation, Quality* and *Cost Effectiveness* as shown in the table below. Brick manufacturers assert that brick has high prestige and natural beauty that cannot be duplicated. Brick manufacturers also offer a staggering number of colors and textures that when used in combination with different mortar colors/styles offer a sizable matrix of design options. Although brick is considered one of the most durable siding materials as rated by builders in a 2002 study (GC&A, 2002), manufacturers under promote this attribute. Brick manufacturers seldom promoted the features/benefits of non-toxicity, wind/impact/corrosion/temperature/sun resistance. Sound deadening capability was also seldom promoted.

Table 40 - Promotional Attribute Ranking, Brick/masonry, combined databases

	Attribute	% of cases mentioning attribute at least once	Mean Freq Per Page (FPP)*		Attribute	% of cases mentioning attribute at least once	Mean Freq Per Page (FPP)*
1	Design Flexibility	87.5%	1.76	16	Energy efficient	17.5%	.08
2	Aesthetics	85.0%	1.20	17	Performs in extreme cond.	17.5%	.08
3	Company/prod. reputation	65.0%	.66	18	Strength	15.0%	.06
4	Quality	60.0%	.69	19	Moisture resistant	12.5%	.04
5	Cost effectiveness	60.0%	.39	20	Weather resistant	12.5%	.05
6	Technologically savvy	42.5%	.36	21	Insect resistant	12.5%	.03
7	Durability	40.0%	.25	22	Sun resistant	12.5%	.03
8	Easy to maintain	37.5%	.28	23	Deadens sounds	10.0%	.03
9	Customer service	32.5%	.34	24	Environmentally friendly	10.0%	.05
10	Easy to install	30.0%	.25	25	Corrosion resistance	7.5%	.01
11	Availability	25.0%	.14	26	Impact resistant	7.5%	.01
12	Code approval/certification	20.0%	.14	27	Dimensional stability	5.0%	.01
13	Warranty offered	20.0%	.21	28	Temperature resistant	5.0%	.02
14	Product integrity	20.0%	.15	29	Wind resistant	5.0%	.01
15	Full product line offered	20.0%	.15	30	Non-toxic	2.5%	.01

Brick/masonry **n = 40 (10 Ads, 2 Brochures, 28 Web sites)**

Fiber cement

Fiber cement manufacturers promoted *Design flexibility, Company/product reputation, Quality, Full product line* and *Cost Effectiveness*. Due to the relative newness of the product, fiber cement manufacturers are likely to promote company/product reputation and quality in order to assure builders that fiber cement performs well. Emphasis on a full product line is found only with fiber cement siding, a benefit not as heavily promoted for other siding materials. Design flexibility is promoted to appeal to multiple applications. For example, James Hardie offers several patterns and textures and promotes the ability to change color as the homeowner desires.

Seldom promoted were the feature/benefits of resistance to wind, temperature, weather, sun, corrosion, and impact. Sun resistance may be counteracted by fiber cement's inert nature but it is a key feature/benefit in fiber cement's strong markets in the southwest. Promoting wind resistance may be an obvious feature/benefit of fiber cement since it is a hefty material. Fiber cement is a ceramic material and manufacturers would have much to gain by promoting its unique temperature resistance. Fiber cement does have some distinguishing installation characteristics related to the product's heavy weight, brittleness and the need for special saw blades to cut the material. Manufacturers currently seldom address ease of installation in promotional materials. Manufacturers can use promotion to offset negative installation perceptions.

Table 41 - Promotional Attribute Ranking, Fiber cement, combined databases

	Attribute	% of cases mentioning attribute at least once	Mean Freq Per Page (FPP)*
1	Design Flexibility	82.4%	3.20
2	Company/prod. reputation	76.5%	2.20
3	Quality	76.5%	.77
4	Full product line offered	76.5%	.69
5	Cost effectiveness	70.6%	.65
6	Aesthetics	52.9%	.80
7	Warranty offered	47.1%	.40
8	Easy to maintain	47.1%	.32
9	Performs in extreme cond.	41.2%	.51
10	Moisture resistant	41.2%	.24
11	Product integrity	29.4%	.21
12	Durability	23.5%	.13
13	Insect resistant	23.5%	.11
14	Dimensional stability	23.5%	.12
15	Strength	23.5%	.15
16	Code approval/certification	17.6%	.10
17	Easy to install	17.6%	.08
18	Technologically savvy	17.6%	.06
19	Weather resistant	17.6%	.02
20	Customer service	11.8%	.10
21	Impact resistant	11.8%	.02
22	Temperature resistant	11.8%	.02
23	Wind resistant	11.8%	.02
24	Environmentally friendly	5.9%	.01
25	Sun resistant	5.9%	.01
26	Availability		
27	Corrosion resistance		
28	Deadens sounds		
29	Energy efficient		
30	Non-toxic		

Fiber cement **n = 17 (12 Ads, 5 Brochures)**

Stucco

Stucco manufacturers promoted *Design flexibility, Aesthetics, Company / product reputation, Quality* and *Product Integrity* most often. Promoting quality and code approval may be a response to past problems with stucco wall system failure. Stucco is the only siding material for which *Code approval* is emphasized in product brochures and Web sites. In addition, manufacturers frequently emphasize the technical details of their products' formulations. This may be to serve the specification requirements of the commercial market. The aesthetic aspects of a stucco exterior are built upon stucco's unique look. Stucco also offers a significant amount of design options from custom colors to multiple surface textures.

Table 42 - Promotional Attribute Ranking, Stucco, combined databases

	Attribute	% of cases mentioning attribute at least once	Mean Freq Per Page (FPP)*		Attribute	% of cases mentioning attribute at least once	Mean Freq Per Page (FPP)*
1	Design flexibility	85.7%	.92	16	Insect/mold resistant	42.9%	.14
2	Aesthetics	85.7%	.30	17	Moisture resistant	28.6%	.10
3	Company/prod. reputation	85.7%	.33	18	Availability	28.6%	.05
4	Quality	71.4%	.77	19	Performs in extreme cond.	14.3%	.14
5	Product integrity	71.4%	.16	20	Full product line offered	14.3%	.14
6	Code approval/certification	57.1%	.53	21	Corrosion resistance	14.3%	.04
7	Cost effectiveness	57.1%	.30	22	Impact resistant	14.3%	.04
8	Customer service	57.1%	.29	23	Strength	14.3%	.04
9	Easy to maintain	57.1%	.27	24	Environmentally friendly	14.3%	.02
10	Durability	57.1%	.27	25	Deadens sound		
11	Technologically savvy	57.1%	.23	26	Dimensional stability		
12	Warranty	42.9%	.27	27	Non-toxic		
13	Easy to install	42.9%	.36	28	Sun/UV/fade resistant		
14	Energy efficient	42.9%	.15	29	Temperature resistant		
15	Weather resistant	42.9%	.14	30	Wind resistant		

Stucco **n = 7 (3 Brochures, 4 Web sites)**

Aluminum

The product features of *Design flexibility*, *Quality*, *Company / product reputation* and *Aesthetics* were promoted most frequently by aluminum siding manufacturers. Aluminum siding producers commonly promote aesthetics via advertising of color richness and variety. Manufacturers also promote the factory baked finishes that are applied to the aluminum substrate emphasizing long lasting color performance. In addition, manufacturers mention chalk resistant properties of their products in direct response to past problems with corrosion.

Numerous attributes – non-toxicity, wind/insect/impact resistance, dimensional stability, sound deadening, etc. – are not found in promotional materials for aluminum siding. Note that only 3 Web sites and 1 product brochure were analyzed for aluminum siding material. No magazine ads for aluminum siding were included in this study, perhaps because residential, not commercial, builders were targeted. Worth noting is that in many instances aluminum manufacturers produce their own lines of vinyl siding.

Table 43 - Promotional Attribute Ranking, Aluminum, combined databases

	Attribute	% of cases mentioning attribute at least once	Mean Freq Per Page (FPP)*		Attribute	% of cases mentioning attribute at least once	Mean Freq Per Page (FPP)*
1	Design flexibility	100%	1.75	16	Performs in extreme cond.	25%	.14
2	Quality	100%	.76	17	Customer service	25%	.05
3	Company/prod. reputation	100%	.56	18	Energy efficient	25%	.05
4	Aesthetics	75%	1.59	19	Moisture resistant	25%	.05
5	Durability	75%	.44	20	Strength	25%	.05
6	Full product line offered	75%	.49	21	Availability		
7	Easy to maintain	75%	.39	22	Corrosion resistance		
8	Warranty	50%	.82	23	Deadens sound		
9	Sun/UV/fade resistant	50%	.29	24	Dimensional stability		
10	Product integrity	50%	.34	25	Easy to install		
11	Technologically savvy	50%	.34	26	Environmentally friendly		
12	Cost effectiveness	50%	.24	27	Impact resistant		
13	Temperature resistant	50%	.19	28	Insect/mold resistant		
14	Code approval/certification	25%	.10	29	Non-toxic		
15	Weather resistant	25%	.10	30	Wind resistant		

Aluminum **n = 4 (1 Brochure, 3 Web sites)**

Steel

Steel siding manufacturers promoted *Aesthetics*, *Design flexibility*, *Quality*, *Strength* and *Code approval*. Strength is a distinguishing attribute for steel siding, and is not promoted heavily for other types of siding material. Steel manufacturers also mention the quality controls employed during the manufacturing process thereby reinforcing product strength and integrity features. Aesthetics may be a must mention feature to reduce negative perceptions of steel since in some forms steel siding can have a utilitarian look. Manufacturers appear to compensate for design limitations by offering a wide array of colors.

Sound deadening capability, dimensional stability, non-toxicity, and temperature resistance were not promoted at all in the brochures and Web sites studied. The least promoted benefits by steel siding manufacturers were wind resistance, weather resistance, sound deadening capability and non-toxicity.

Table 44 - Promotional Attribute Ranking, Steel, combined databases

	Attribute	% of cases mentioning attribute at least once	Mean Freq Per Page (FPP)*		Attribute	% of cases mentioning attribute at least once	Mean Freq Per Page (FPP)*
1	Aesthetics	100%	1.61	16	Easy to maintain	22.2%	.16
2	Design flexibility	88.9%	1.62	17	Technologically savvy	22.2%	.22
3	Quality	77.8%	.67	18	Wind resistant	22.2%	.19
4	Strength	66.7%	1.04	19	Impact resistant	22.2%	.13
5	Code approval/certification	66.7%	.46	20	Availability	22.2%	.05
6	Easy to install	55.6%	.55	21	Full product line offered	22.2%	.07
7	Cost effectiveness	55.6%	.51	22	Product integrity	22.2%	.09
8	Weather resistant	55.6%	.48	23	Performs in extreme cond.	11.1%	.22
9	Warranty	55.6%	.46	24	Insect/mold resistant	11.1%	.19
10	Corrosion resistance	44.4%	.39	25	Energy efficient	11.1%	.03
11	Durability	44.4%	.38	26	Sun/UV/fade resistant	11.1%	.06
12	Moisture resistant	33.3%	.44	27	Deadens sound		
13	Environmentally friendly	22.2%	.33	28	Dimensional stability		
14	Customer service	22.2%	.13	29	Non-toxic		
15	Company/product reputation	22.2%	.20	30	Temperature resistant		

Steel **n = 9 (4 Brochures, 5 Web sites)**

Magazine Advertisements vs. Brochure / Web Gap Analysis

Promotional frequency in magazine advertisements is compared to promotional frequency in product brochures (or Web pages where product brochures were not available). Refer to the METHODS section in this report for details regarding the magazine advertisement and Web/brochure databases. Some feature/benefit categories showed significant differences in promotional frequency for the two communication methods, while many showed minimal variation in rate of promotion. This section discusses attributes for which this gap analysis found notable differences between the two databases. Attributes for which there was little difference are not discussed here, but data can be found in *APPENDIX I - Additional Data Charts for Ad vs. Brochure Gap Analysis*. Most notable differences between the two communication mediums were for categories of Aesthetics, Design Flexibility, and Product/Company reputation.

For example, for brick siding *Reputation* is more heavily promoted in brochures and Web pages than in magazine advertisements. Aesthetics is promoted more frequently in magazine ads for wood composite and brick. The remainder of this section discusses in more detail each attribute where gaps are noted.

Ad frequencies were not weighted, but brochure / Web frequencies were weighted to reflect frequency per page due to use of multiple pages. Steel, aluminum and stucco siding brands were not included in the brochure / Web database since none of the residential building magazines studied advertised those siding materials. Z-scores were calculated for each database and were used as the basis of comparison. Use of z-scores eliminated disparities due to use of multiple pages and weighting in the brochure / Web database.

For example,

Ads: L-P Norman Rockwell, 2 ads, 5 Aesthetics mentions in each. (probably the same ad, 2 different magazines)

Brochures/Web: L-P Norman Rockwell brochure, 8 pages, 6 Aesthetics mentions; weighted score for Aesthetics is: .75

Doesn't make sense to say that for Ads, Aesthetics is mentioned 5 times per page, but for Brochures/Web it's only mentioned .75 times per page. Z-scores eliminate this problem since z-scores reflect standard deviation from mean and are calculated separately for the Ad database and the Brochures / Web database.

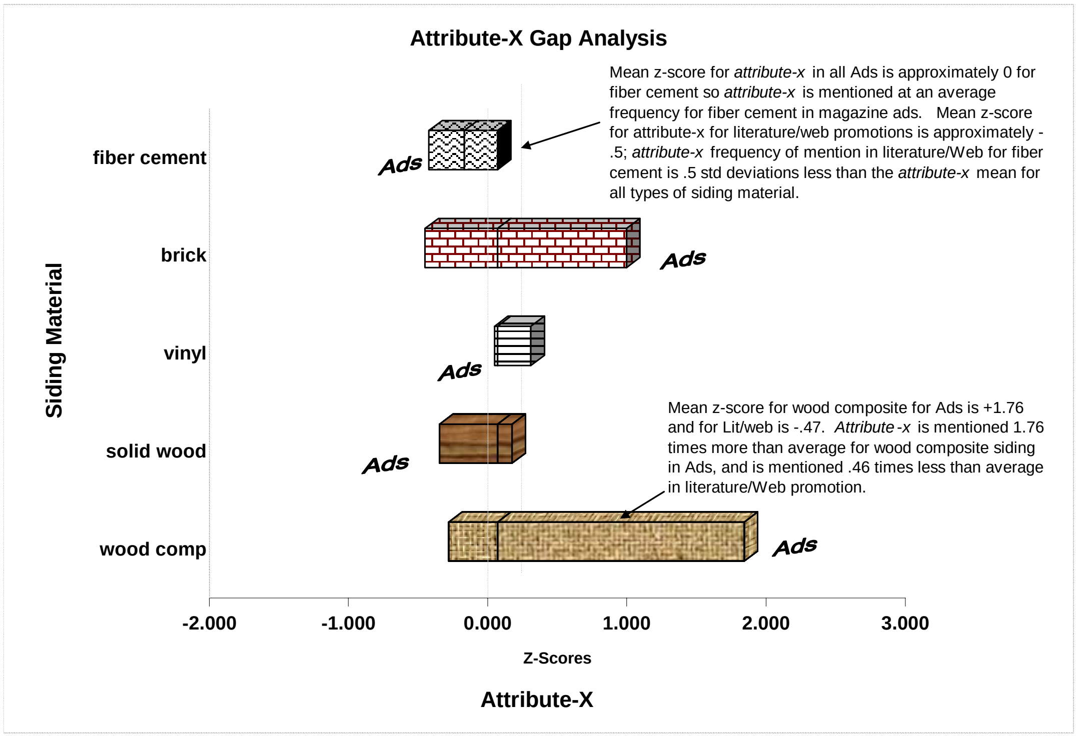
No magazine advertisements were found in the targeted residential builder magazines for steel, aluminum or stucco siding; therefore, these categories are not included in this gap analysis.

Table 45 – Ad and Web/brochure counts by siding material

Siding Material	Magazine Advertisement Count	Web / Brochure Count
vinyl	44	73
solid wood	22	26
brick/masonry	10	30
fiber cement	12	5
wood composite	2	6
Total	**90**	**140**

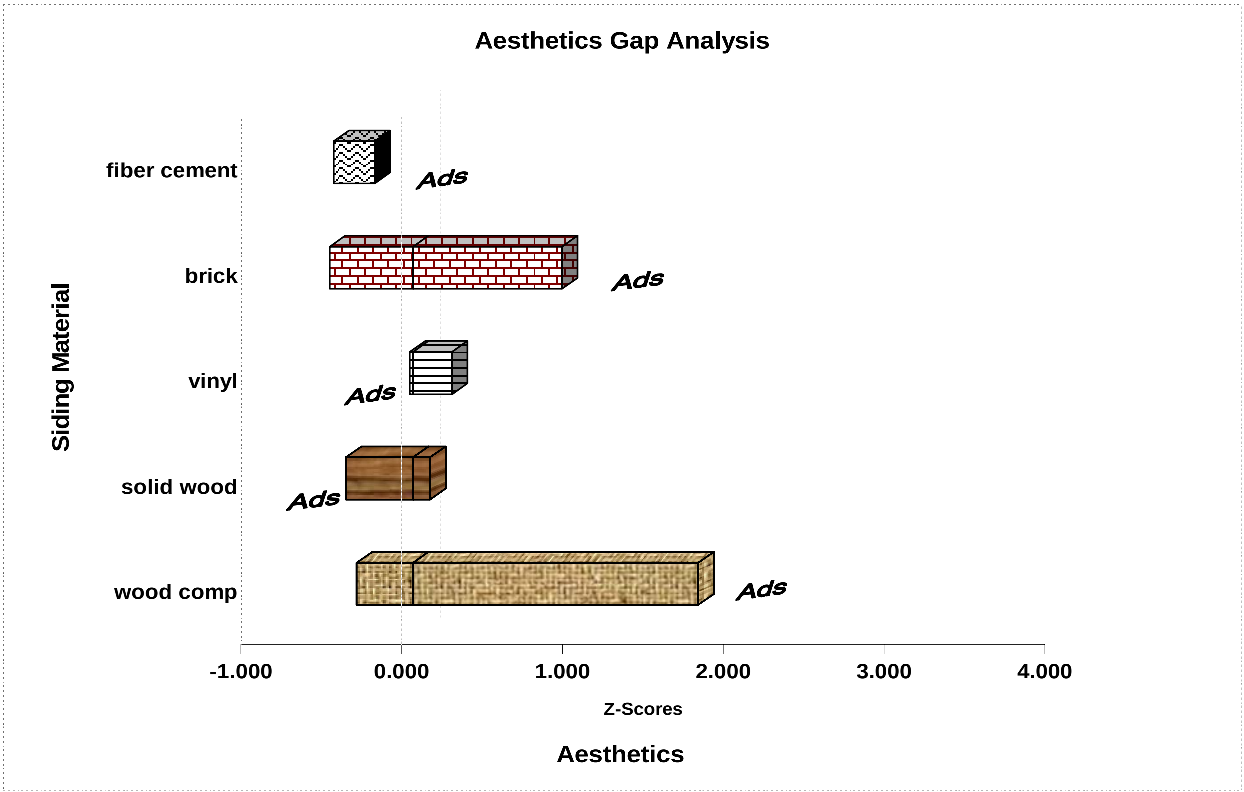
Interpretation of Gap Analysis charts

Sample chart:



Aesthetics

The Aesthetics category captured all manufacturer claims of product beauty, desired looks, curb appeal or attractive exterior.

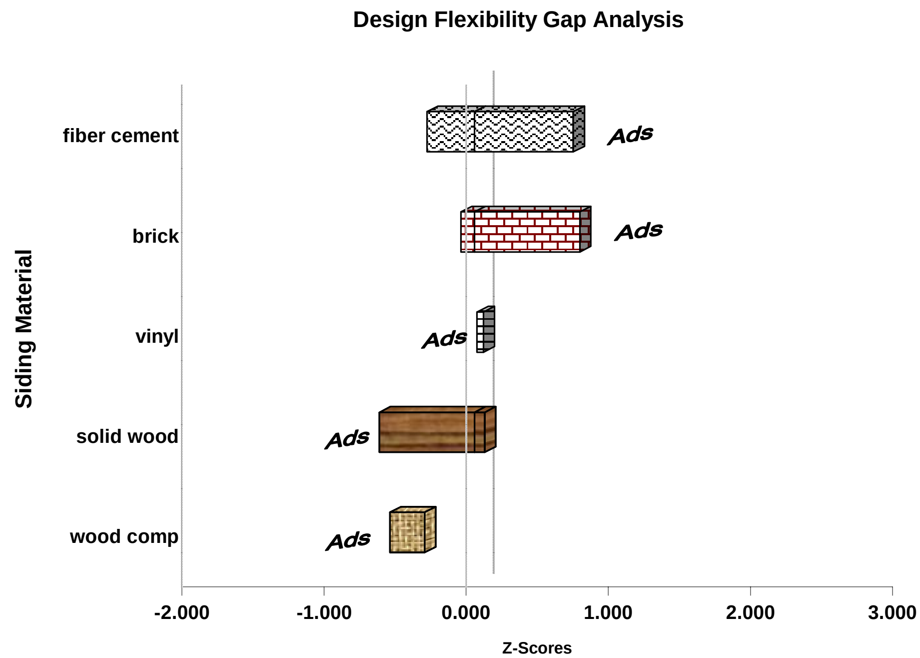


Manufacturers tend to promote Aesthetics more frequently in magazine advertisements than in product brochures or Web pages for wood composite and brick siding. Note that only 2 advertisements for wood composite siding were included in this study.

AESTHETICS						
	Advertisements			Brochure / WWW Weighted per Page		
Siding material	**N**	**Mean**	**Median**	**N**	**Mean**	**Median**
fiber cement	**12**	.91	.0	**5**	.73	.73
brick/masonry	**10**	2.70	2.0	**30**	.70	.67
vinyl	**44**	1.24	1.0	**73**	1.67	1.33
solid wood	**22**	.64	1.0	**26**	1.50	1.29
wood composite	**2**	4.00	4.0	**6**	.92	1.00
Total	**90**	1.28	1.0	**140**	1.37	1.00

Design flexibility

Design flexibility describes the ability of a siding material to be incorporated within numerous architectural styles, housing designs and siding layout schemes. Design flexibility was the most promoted attribute for all categories of siding materials.



Design Flexibility

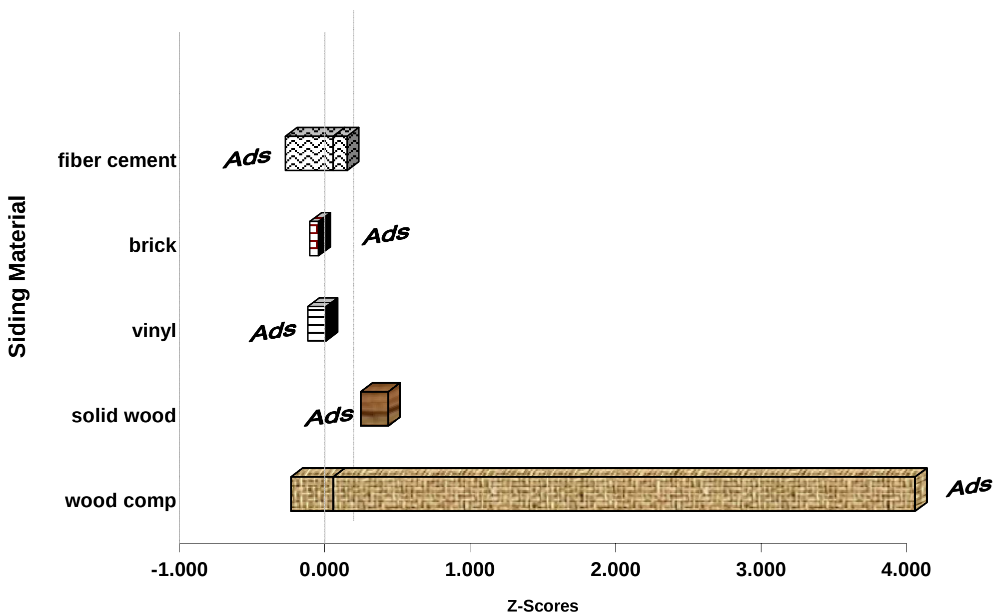
Design flexibility is promoted more frequently in magazine advertisements for fiber cement and brick siding.

DESIGN FLEXIBILITY						
	Advertisements			Brochure / WWW		
					Weighted per Page	
Siding material	**N**	**Mean**	**Median**	**N**	**Mean**	**Median**
fiber cement	**12**	4.09	6.0	**5**	.67	.55
brick/masonry	**10**	4.20	4.0	**30**	.95	.92
vinyl	**44**	2.47	2.0	**73**	1.14	1.00
solid wood	**22**	.82	1.0	**26**	1.15	.75
wood composite	**2**	1.00	1.0	**6**	.65	.82
Total	**90**	2.42	1.0	**140**	1.07	.87

Durability

Product durability is a material's resistance to failure over a long period of time. Durability can be viewed as a multiplicative function that includes such factors as temperature resistance, weather resistance, moisture resistance, air resistance and UV resistance.

Durability Gap Analysis



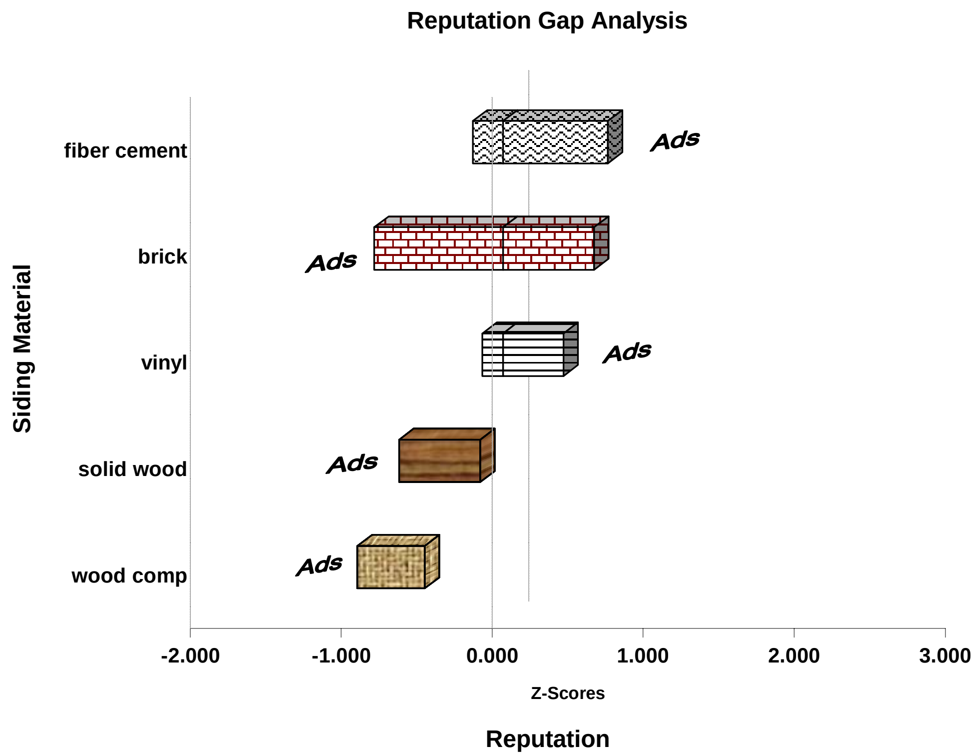
Durability

Durability is promoted more frequently in magazine advertisements for wood composite siding.   Note that only 2magazine advertisements for wood composite siding were included in this study.

DURABILITY						
	Advertisements			Brochure / WWW Weighted per Page		
Siding material	**N**	**Mean**	**Median**	**N**	**Mean**	**Median**
fiber cement	**12**	0	0	**5**	.67	.55
brick/masonry	**10**	.1	0	**30**	.95	.92
vinyl	**44**	.07	0	**73**	1.14	1.00
solid wood	**22**	.23	0	**26**	1.15	.75
wood composite	**2**	2.00	2.0	**6**	.65	.82
Total	**90**	.14	0	**140**	.39	.25

Product / company reputation

Company or product reputation includes promotional references that strengthen the legitimacy of a siding manufacturer and its products.

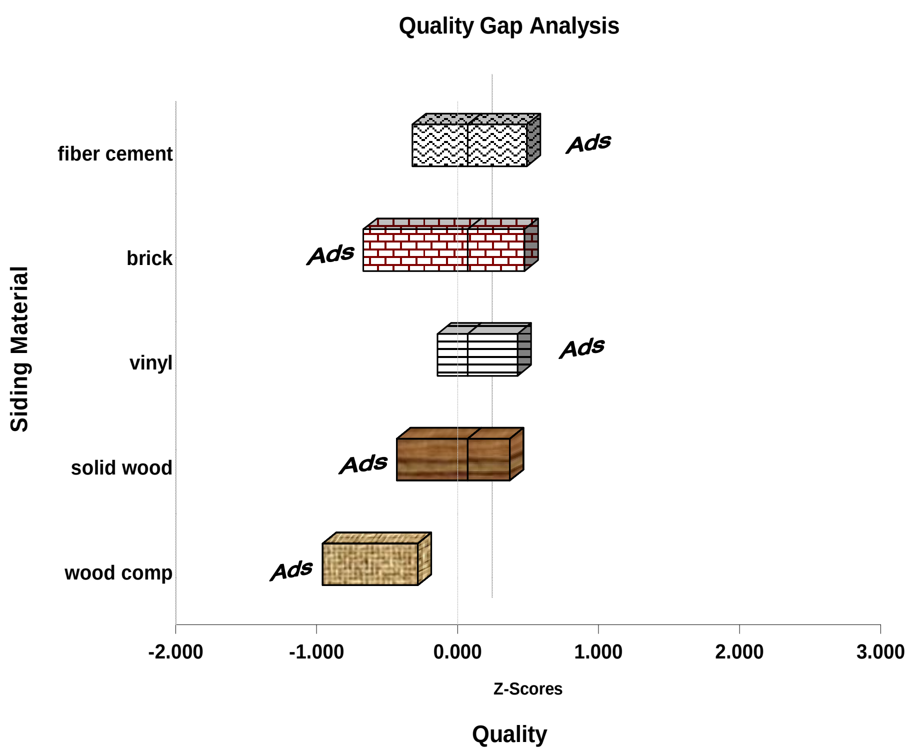


REPUTATION						
	Advertisements			Brochure / WWW Weighted per Page		
Siding material	**N**	**Mean**	**Median**	**N**	**Mean**	**Median**
fiber cement	**12**	3.00	3.00	**5**	.29	.00
brick/masonry	**10**	.20	.00	**30**	.81	.67
vinyl	**44**	2.47	3.00	**73**	.33	.09
solid wood	**22**	.50	.00	**26**	.32	.08
wood composite	**2**	.00	.00	**6**	.08	.00
Total	**90**	1.74	1.00	**140**	.42	.13

Reputation is seldom promoted in product brochures / Web for fiber cement and vinyl siding, but is heavily promoted in magazine advertisements. For brick siding, reputation is more heavily promoted in brochures and Web pages than in magazine advertisements.

Quality

The Quality attribute captures references to quality across all facets of a manufacturer's operations from product quality to quality control in operations.

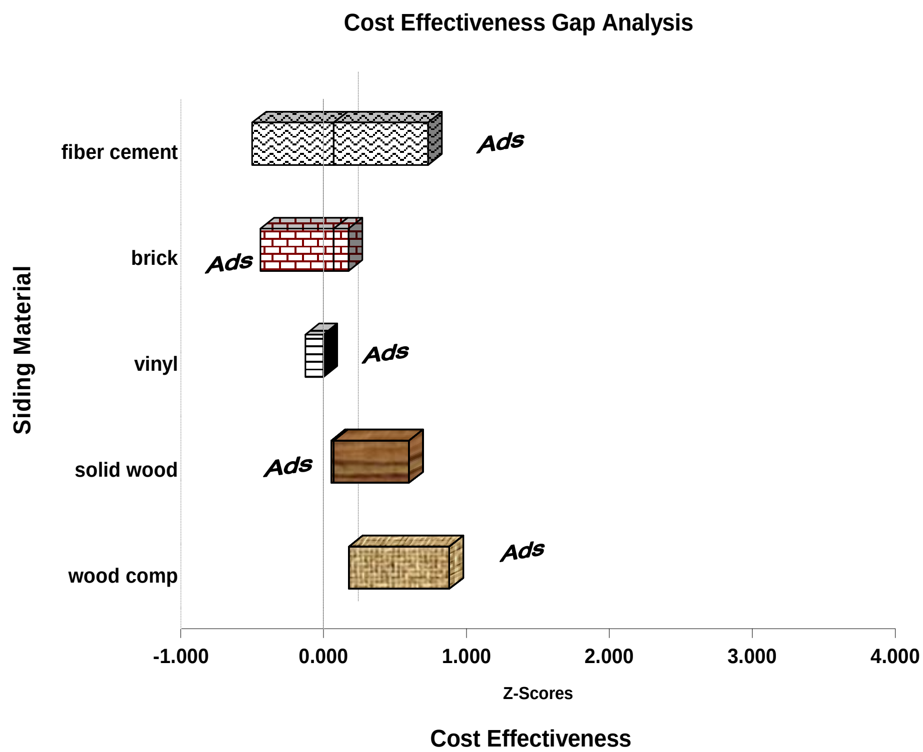


Quality is promoted more frequently in magazine advertisements for fiber cement and vinyl siding, and is promoted more frequently in product brochures or Web pages for brick, solid wood and wood composite siding.

QUALITY						
	Advertisements			Brochures / WWW Weighted per Page		
Siding material	**N**	**Mean**	**Median**	**N**	**Mean**	**Median**
fiber cement	**12**	1.00	1.00	**5**	.22	.00
brick/masonry	**10**	.20	.00	**30**	.85	.63
vinyl	**44**	.96	1.00	**73**	.36	.25
solid wood	**22**	.36	.00	**26**	.77	.44
wood composite	**2**	.00	.00	**6**	.25	.10
Total	**90**	.71	1.00	**140**	.53	.38

Cost Effectiveness

Cost effectiveness can be viewed as an additive function that captures the total cost of purchase, installation and disposal of a siding product. For example, factors that are included in cost effectiveness are purchase cost, the installation cost (labor skill level, amount and pay rate, etc.), product waste generated, life maintenance costs and the cost of product removal and disposal.

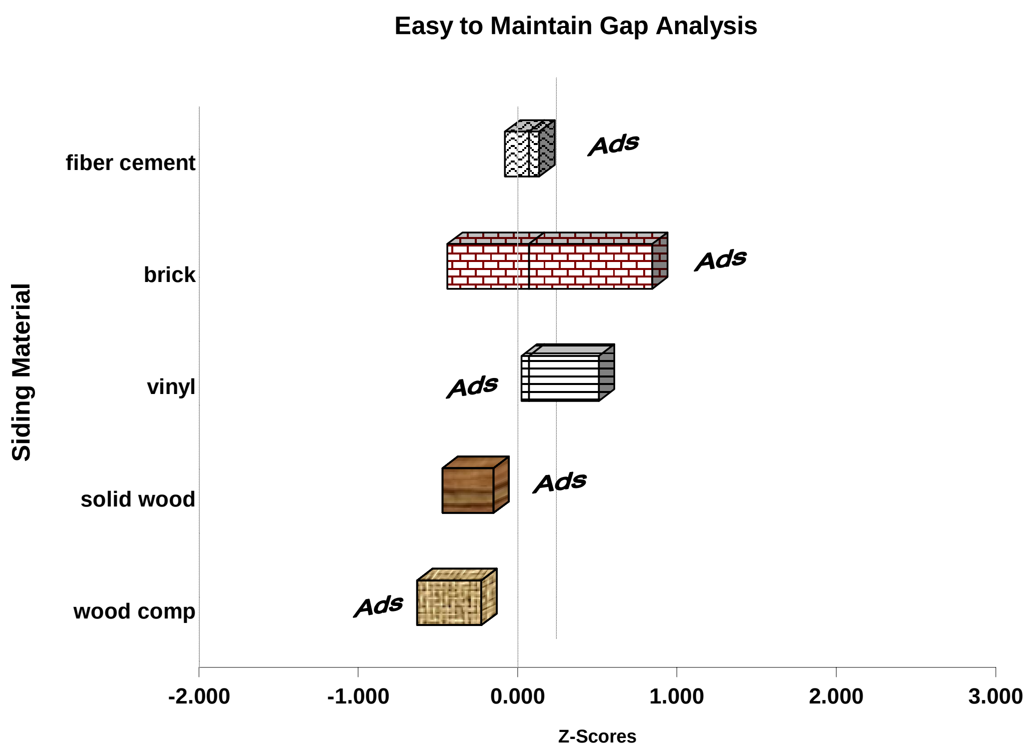


Cost effectiveness is promoted more frequently in magazine advertisements for fiber cement siding and for wood composite siding.

COST EFFECTIVENESS						
	Advertisements			Brochures / WWW Weighted per Page		
Siding material	N	Mean	Median	N	Mean	Median
fiber cement	12	.91	1.00	5	.03	.00
brick/masonry	10	.20	.00	30	.46	.00
vinyl	44	.47	.00	73	.26	.13
solid wood	22	.50	.00	26	.73	.33
wood composite	2	1.00	1.00	6	.46	.35
Total	90	.51	.00	140	.39	.17

Easy to Maintain

Siding products that require low maintenance or care after being installed offer the feature/benefit of low maintenance.



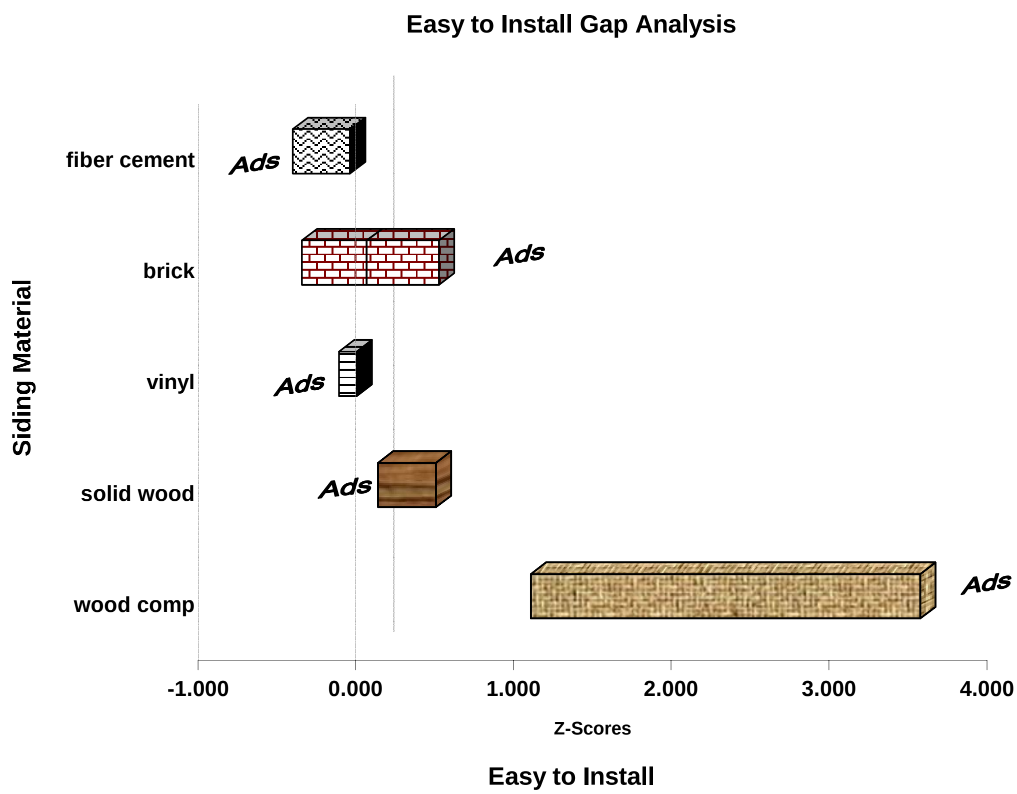
Easy to Maintain

Ease of Maintenance is promoted more frequently in magazine advertisements for brick/masonry siding.

EASY TO MAINTAIN						
	Advertisements			Brochures / WWW Weighted per Page		
Siding material	**N**	**Mean**	**Median**	**N**	**Mean**	**Median**
fiber cement	**12**	.36	.00	**5**	.29	.13
brick/masonry	**10**	.70	1.00	**30**	.13	.00
vinyl	**44**	.31	.00	**73**	.54	.50
solid wood	**22**	.23	.00	**26**	.12	.00
wood composite	**2**	.00	.00	**6**	.22	.16
Total	**90**	.33	.00	**140**	.35	.21

Easy to Install

This attribute captures all references that imply that the product is easier to install, use or handle during the construction process.



Ease of Installation is promoted much more frequently in magazine advertisements for wood composite siding. Installation Ease is also more heavily promoted by brick manufacturers in magazine ads.

EASY TO INSTALL						
	Advertisements			Brochures / WWW Weighted per Page		
Siding material	N	Mean	Median	N	Mean	Median
fiber cement	12	.00	.00	5	.26	.19
brick/masonry	10	.70	1.00	30	.10	.00
vinyl	44	.22	.00	73	.29	.09
solid wood	22	.41	.00	26	.56	.08
wood composite	2	3.00	3.00	6	.88	.68
Total	90	.36	.00	140	.32	.00

Builder-Manufacturer Gap Analyses

A builder-manufacturer gap analysis compared 7 siding attributes based on 2002 builder performance ratings and 2005 manufacturers' frequency of promotion. Analysis of builder performance ratings for the 7 shared siding attributes is included in this section. Data was aggregated by siding material category for further analysis. Manufacturer and builder siding category attribute scores were standardized for direct comparison.

Builder Data

The builder siding data was collected by George Carter and Associates and Resource Information Systems Inc. (RISI) in 2002.18 A sample of 700 builders was identified from U.S. building material association lists. Builders were contacted in the spring of 2002 to examine the key purchase criteria and performance characteristics of various siding materials. Builders were presented with specific attributes and were asked to rate each attribute's importance to purchase decisions on a scale from 0 to 10, where 0 = not at all important, and 10 = very important. Builders were asked to rate the same characteristics in terms of performance. Performance ratings were indicated on a scale from –5 to +5 where –5 = extremely bad performance, 0 = neutral performance, and +5 = extremely good performance.

Manufacturer Data

Research at Pennsylvania State University included software-based textual analysis to identify and code 30 product attributes promoted by 99 siding manufacturers producing over 160 brands of siding. Two data sources were analyzed: 1) siding manufacturer product brochures or Web pages, and 2) siding advertisements in 6 builder-focused trade magazines, each with circulation over 63,400. Data sources were collected and analyzed during the first quarter of 2005. Frequency of mentions of particular attributes was recorded for 90 magazine advertisements and for 160 product brochures (or Web pages if product brochures were not available). The researcher reviewed each document to identify any strings of text representing one of the 30 attributes, and tagged strings using a software-based textual analysis program. Because most advertisements were for 1 page or less while brochures contained multiple pages, mean number of mentions per page for product brochures was calculated and used in the gap analysis.

Limitations

The builder data is not as robust as the manufacturer data; therefore, we could only compare 7 attributes for 7 of the siding material categories. Only 1 builder responded for brick and 1 for stucco.

Builders rated performance for specific attributes (on a –5 to +5 scale), and only for attributes listed in the survey. In their promotional literature, manufacturers may aim to educate consumers or to differentiate their product from like products. They will promote the attributes deemed most likely to convince consumers to purchase their product. In some cases, certain products may already be widely perceived as owning particular attributes. For example, brick is considered a

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[18] The builder data was collected independently and was not funded by the ONR Grant.

high quality siding material at higher cost, but 7 of 8 manufacturers advertising brick siding did not promote the Quality/Status attribute.

If a manufacturer didn't mention an attribute in its advertising, then that manufacturer does not necessarily consider the attribute not to be important; i.e., 'no mentions' does not equal 'not at all important'. Manufacturers may attempt to differentiate a siding product by excessively promoting a particular attribute; for example, Boral Brick and Owens Corning heavily promote *Design Flexibility* for their brick and stone siding respectively, but most solid wood siding manufacturers advertise *Design Flexibility* little if at all. Moreover, builders were not asked to rate *Design Flexibility* in the 2002 study so importance of these attributes can't be compared.

Manufacturers may choose to use advertising space to promote attributes that builders weren't questioned about in the survey (e.g., *Technological savvy, Sound deadening/insulation, Certification/code approval, etc.* Reference Table 46).

Attributes promoted by graphics were not identified for the manufacturer promotion study. Graphics may be used to portray curb appeal (aesthetics), variety of styles, warranty seals, and other features.

Variation of font style used for text strings was not considered in the text analysis of manufacturer promotion. For example, bold or italicized text may indicate higher promotional importance to the manufacturer.

Attribute Selection

Seven common attributes were selected for comparison. Attributes were combined and matched as illustrated in Table 46 below. Where multiple promotional attributes were categorized as one attribute (*Damage/Impact resistance* and *Durability*), frequencies were summed in the manufacturer promotional databases.

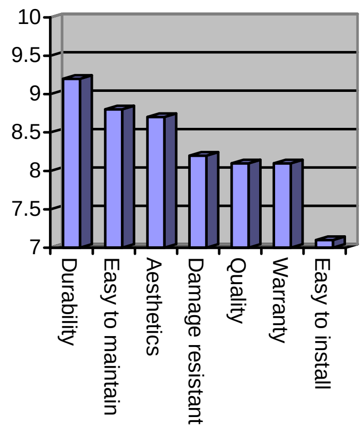
Table 46- Siding attributes common to builder purchase and manufacturer promotion

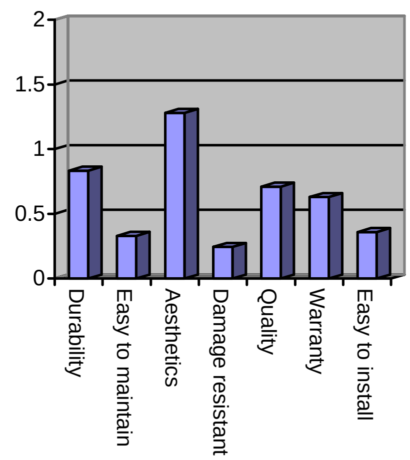
	Shared Attribute n = 7	**Mfr Promotion** n = 30	**Builder Performance** n = 16
1	Aesthetics	Aesthetics	Curb appeal
2	Durability	Dimensional stability	Durability or Long-term performance
		Durability	
		Product integrity	
		Insect/mold resistance	
		Moisture resistance	
		Corrosion resistance	
		Sun/UV resistance	
		Temperature resistance	
		Weather resistance	
3	Easy to install	Ease of installation	Easy to install
4	Easy to maintain	Ease of maintenance	Low maintenance
5	Quality	Quality	Status or quality image
6	Warranty	Warranty offered	Mfr warranty
7	Damage/Impact resistance	Impact resistance	Damage or Impact resistance
		Performs in extreme situations	
		Wind resistance	
		Availability	*No correlating Builder purchase attribute*
		Certification/code approval	
		Cost effective / economical	
		Customer Service	
		Deadens/insulates sound	
		Design flexibility	
		Energy efficiency	
		Environmentally friendly	
		Full product line offered	
		Non-toxicity	
		Sound reputation	
		Strength	
		Technological savvy	
		No correlating Mfr promotional attribute	Customer request or demand
			Installation cost
		Related to Distribution – no match	Availability
			Dealer terms
			On-time delivery
			Purchase price
			Reduce customer complaints
			Sales Rep Contact
			Variety of styles

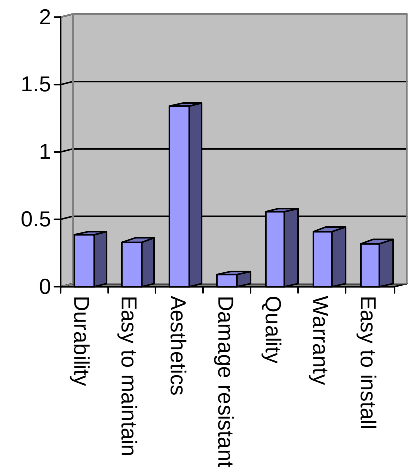
Gap Analysis by Siding Material

All Siding – Purchase Importance to Builders vs. Manufacturer Promotion

Table 47 – Manufacturer Promotion vs. Builder Purchase Importance (0 to 10), All Siding

<table>
<tr><th></th><th>BUILDER PURCHASE</th><th>MAGAZINE ADVERTISEMENTS</th><th>BROCHURES / WEB</th></tr>
<tr><td>ALL SIDING</td><td>

n = 116 to 121[19]</td><td>

n=90</td><td>

n=160</td></tr>
</table>

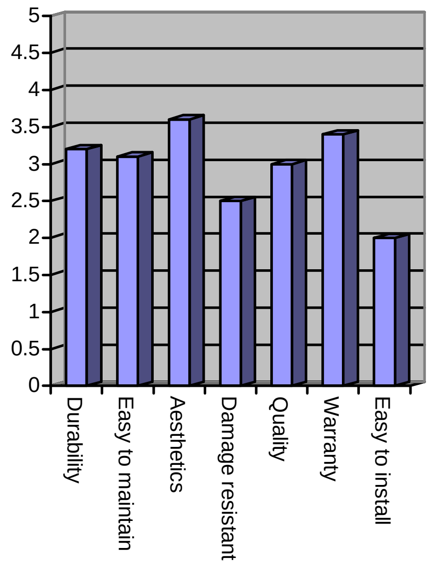
Builders consider *Durability* to be the most important of these 7 attributes[20] when considering what type of siding to purchase. Of the 7 shared attributes, manufacturers most often promote *Aesthetics* in both magazine advertisements and in product brochures. Builders rated *Ease of Installation* as the least important purchase consideration. Builder data for purchase importance ratings was not available by type of siding material.

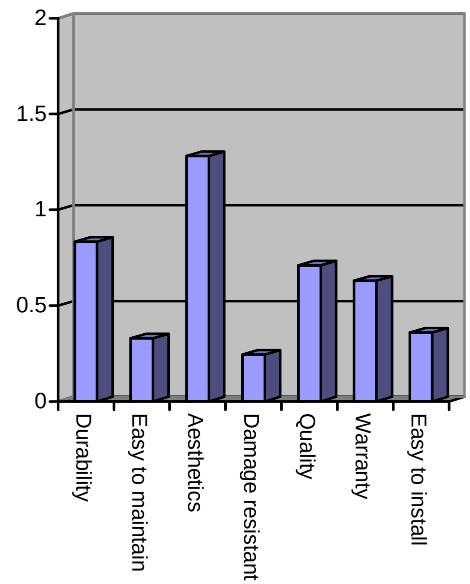
[19] Of 652 respondents, n = the number of respondents indicating an importance rating for given attributes. For these attributes, number of respondents was between 116 and 121 for each attribute.

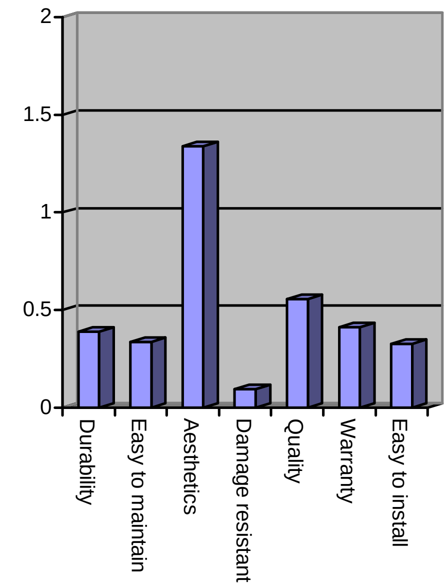
[20] Thirty promotional attributes were analyzed but only the attributes in common with the builder study are included here. Other attributes such as *Design Flexibility* were also promoted frequently.

All Siding – Performance as rated by Builders vs. Manufacturer Promotion

Table 48 - Manufacturer Promotion vs. Builder Performance Rating (-5 to +5), All Siding

<table>
<tr><th></th><th>BUILDER PERFORMANCE</th><th>MAGAZINE ADVERTISEMENTS</th><th>BROCHURES / WEB</th></tr>
<tr><td>ALL SIDING</td><td>

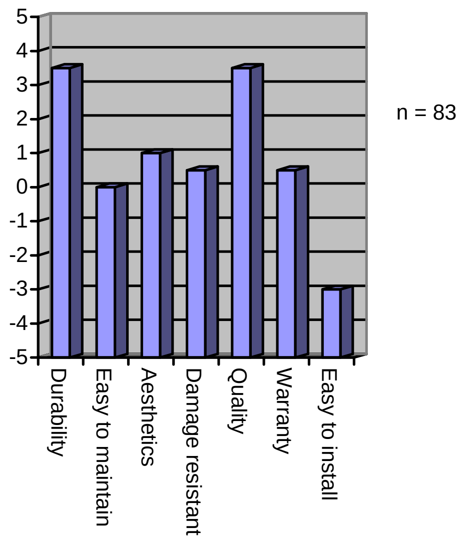
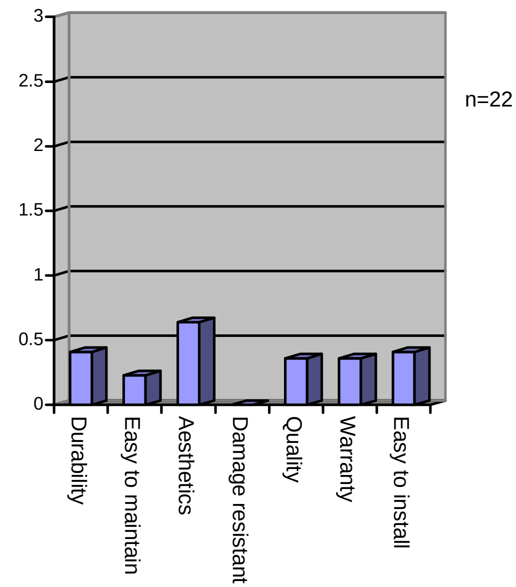
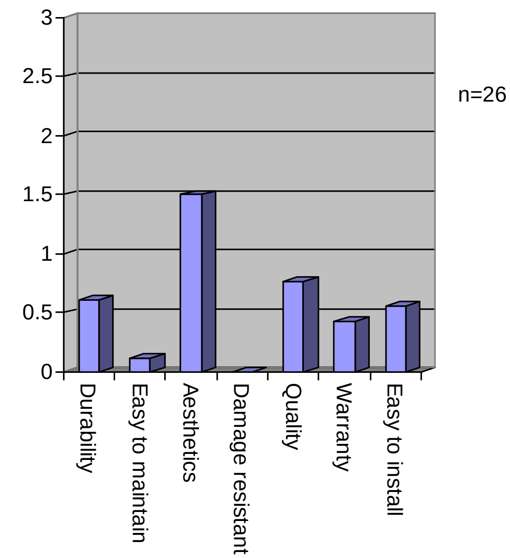
n = 83</td><td>

n=90</td><td>

n=160</td></tr>
</table>

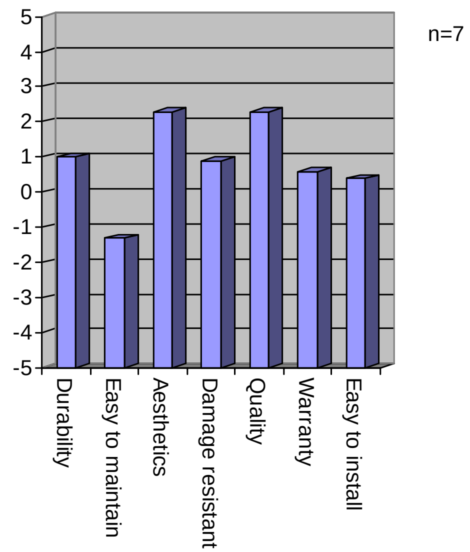
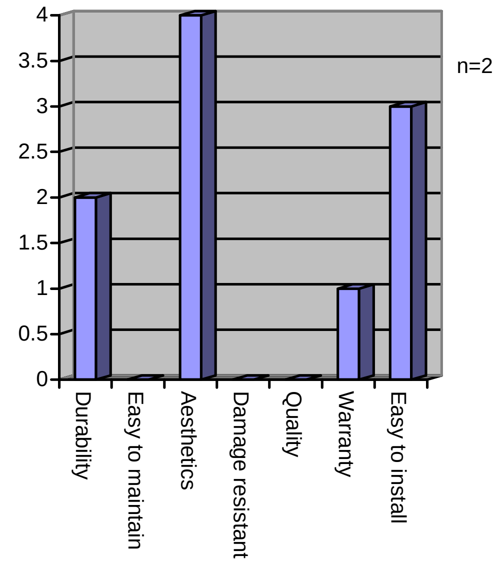
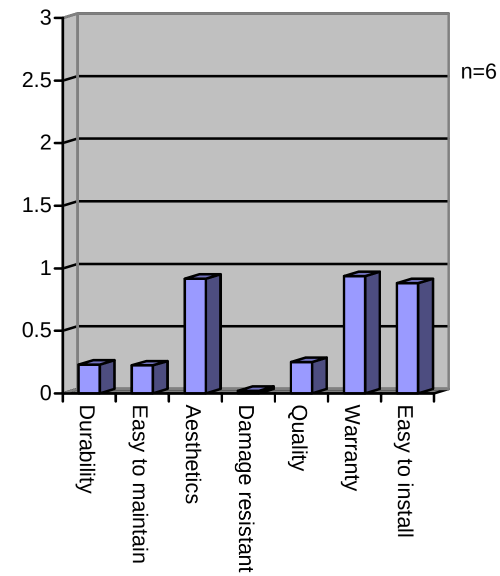
For all types of siding material, builders ranked *Aesthetics* and *Warranty* as performing just slightly higher than the other 5 attributes. Builders rated *Ease of Installation* less favorably than other attributes. However, builders also rated *Ease of Installation* as the least important feature when making purchasing decisions. For all types of siding, manufacturers most often promote *Aesthetics* in both magazine ads and in product brochures. *Design Flexibility* is also heavily promoted by manufacturers but was not an attribute included in the Builder survey.

Solid Wood

	BUILDER PERFORMANCE RATING	MANUFACTURER MAGAZINE ADS	MANUFACTURER BROCHURES / WEB
SOLID WOOD			

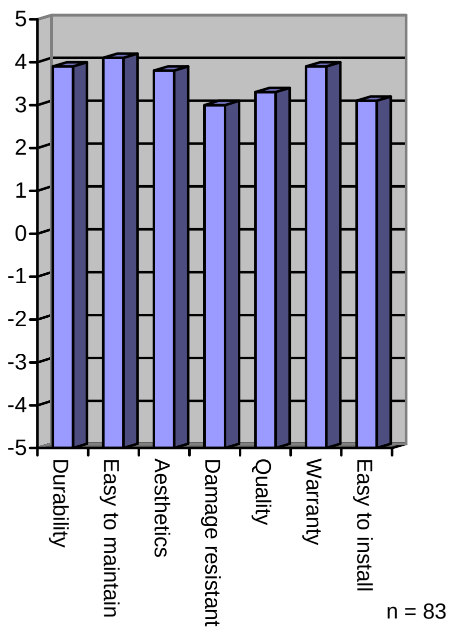
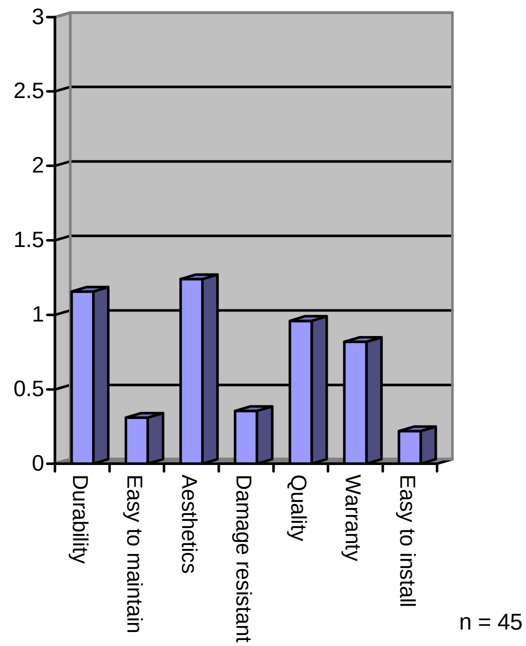
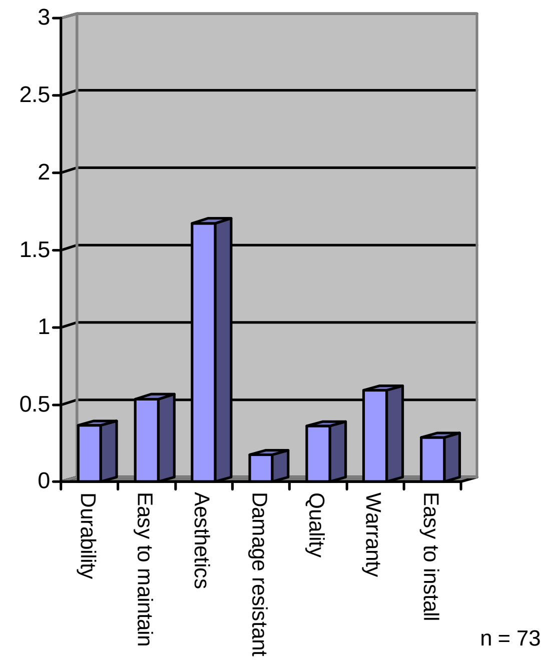
Builders ranked ***Durability*** and ***Quality*** (status or image) performance attributes highest for solid wood siding. Manufacturers of solid wood siding most often promoted ***Durability***, particularly in product brochures or Web pages, followed by ***Aesthetics***. ***Quality*** was not emphasized in magazine advertisements. The poor performance rating for ***Ease of installation*** would suggest that manufacturers should address and/or promote ease of installation for solid wood siding. Comparison of performance ratings for solid wood to ratings for vinyl and fiber cement suggest that one or more of ***Ease of maintenance, Aesthetics, Damage Resistance*** and ***Warranty*** attributes be promoted. Worth noting is that the mean size of magazine ads for solid wood siding was 34in^2 at an ad rate of \$6,347 while mean size for vinyl siding ads was 107in^2 at a rate of \$19,425.

Wood Composite

	BUILDER PERFORMANCE RATING	MANUFACTURER MAGAZINE ADS	MANUFACTURER BROCHURES / WEB
WOOD COMPOSITE			

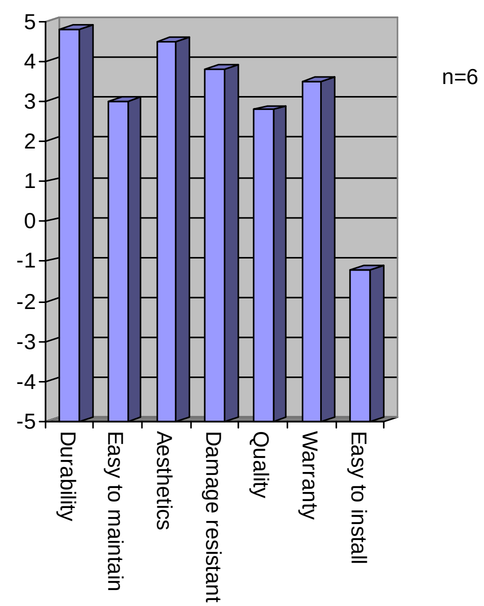
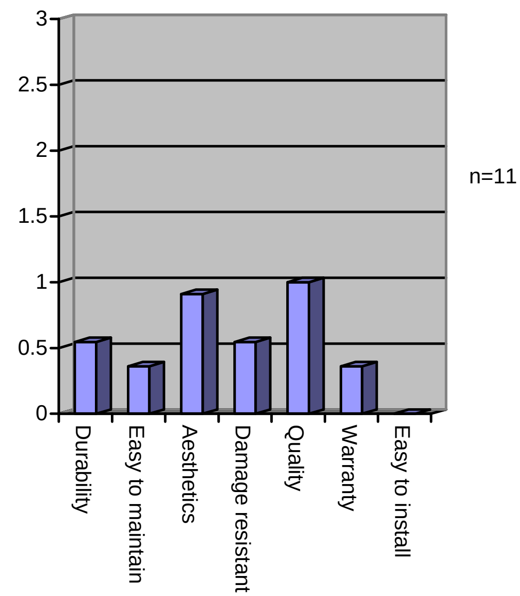
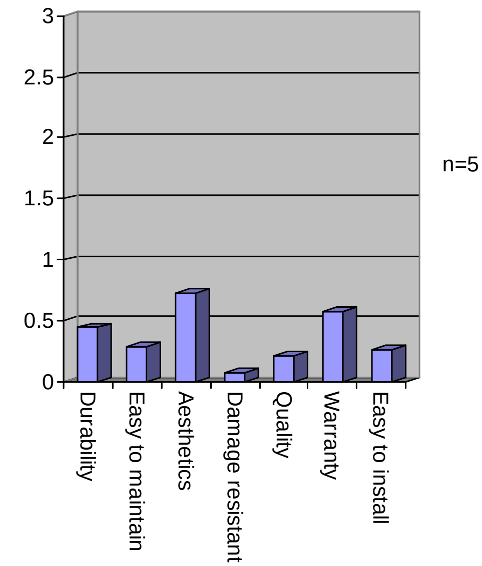
Seven builders (2 OSB, 5 Hardboard) ranked *Aesthetics* and *Quality* (status) as the best performing attributes for wood composite siding. Performance ratings for wood composite siding were lower overall than for vinyl or fiber cement siding. The two manufacturers advertising wood composite siding promoted *Aesthetics* and *Easy to install* most often. The six manufacturers with product brochures (or Web pages) most frequently mentioned *Aesthetics* and *Warranty*. The *Easy to maintain* attribute was seldom promoted by wood composite siding manufacturers and was rated as a poor performance attribute by builders.

Vinyl

	BUILDER PERFORMANCE RATING	MANUFACTURER MAGAZINE ADS	MANUFACTURER BROCHURES / WEB
V I N Y L			

Of the 83 builders indicating performance ratings for vinyl siding, performance for all 7 attributes was rated from very good to extremely good. Of these 7 attributes, manufacturers most often promoted ***Aesthetics*** for vinyl siding. Since performance ratings for all attributes were favorable, vinyl siding manufacturers can highlight particular attributes to differentiate their vinyl siding from other siding products.

Fiber Cement

	BUILDER PERFORMANCE RATING	MANUFACTURER MAGAZINE ADS	MANUFACTURER BROCHURES / WEB
FIBERCEMENT			

Of the 6 builders who supplied performance ratings for fiber cement siding, all attributes except ***Easy to Install*** were ranked as having very good to extremely good performance. Manufacturers most often promoted ***Aesthetics*** and ***Quality*** in magazine advertisements, while ***Aesthetics*** and ***Warranty*** were most often cited in product brochures or Web pages. The poor performance rating for ***Ease of Installation*** would suggest that manufacturers should address and/or promote ease of installation for fiber cement siding. Of the 11 magazine advertisements for fiber cement siding, none promoted ***Ease of Installation***.

Brick / Masonry

<table>
<tr><th></th><th>BUILDER
PERFORMANCE RATING</th><th>MANUFACTURER
MAGAZINE ADS</th><th>MANUFACTURER
BROCHURES / WEB</th></tr>
<tr><td>B
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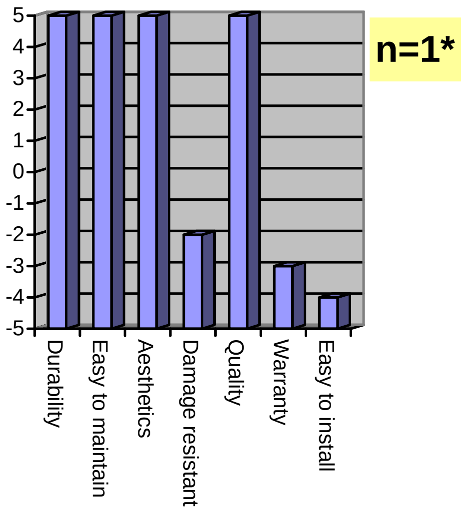
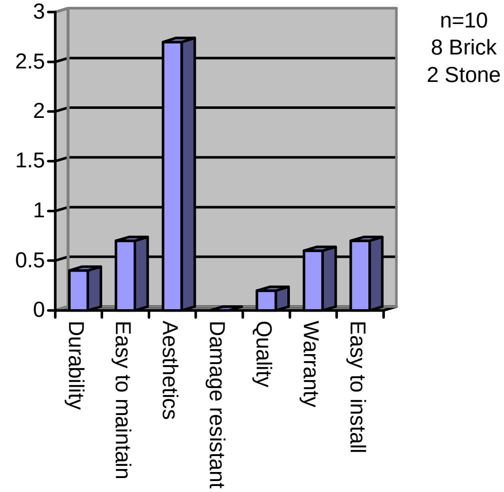
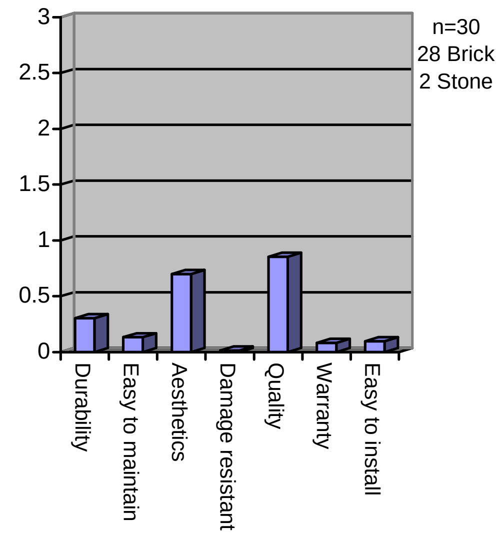
<td>
</td>
<td>
</td>
<td>
</td></tr>
</table>

*Note: Only one builder responded to questions about brick attributes.

Manufacturers most often advertise ***Aesthetics*** for brick in magazine advertisements. In product brochures, ***Quality***, followed by ***Aesthetics*** and ***Durability*** are most frequently cited for brick.

Stucco

<table>
<tr><th></th><th>BUILDER
PERFORMANCE RATING</th><th>MANUFACTURER
MAGAZINE ADS</th><th>MANUFACTURER
BROCHURES / WEB</th></tr>
<tr><td>S
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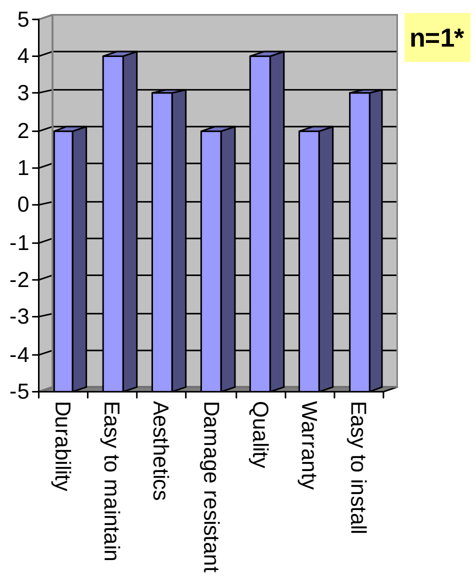
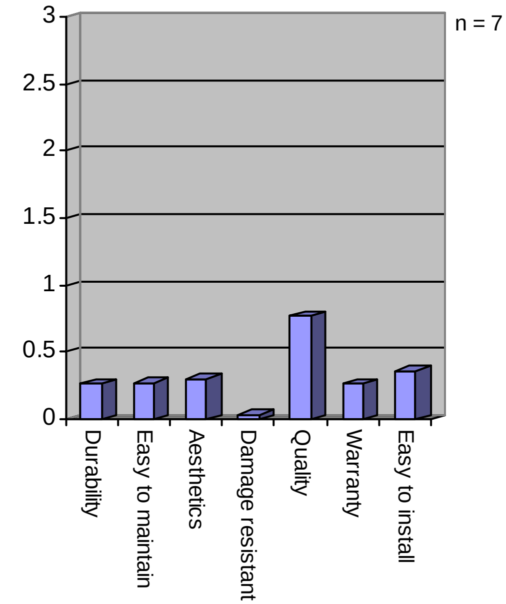
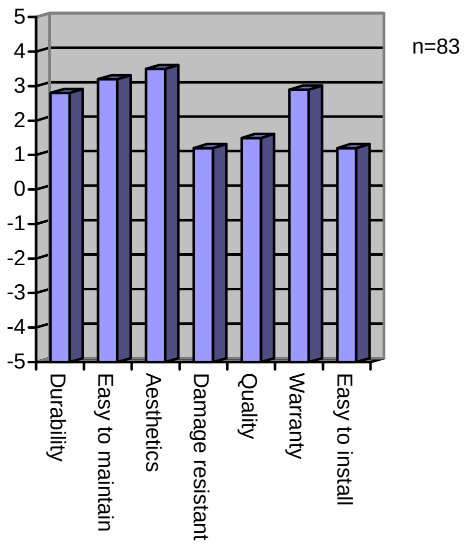
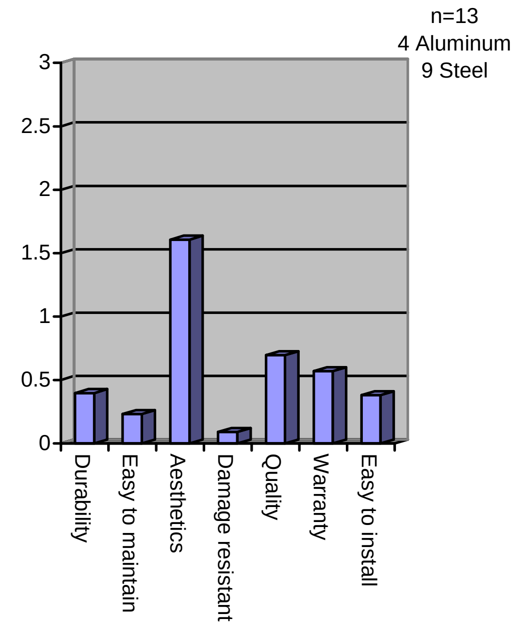
O</td><td>
</td><td>No Stucco siding magazine advertisements were recorded for first quarter, 2005.</td><td>
</td></tr>
</table>

*Note: Only one builder responded to questions about stucco attributes.

Manufacturers most often promote ***Quality*** for stucco siding in product brochures.

Aluminum / Steel

	BUILDER PERFORMANCE RATING	MANUFACTURER MAGAZINE ADS	MANUFACTURER BROCHURES / WEB
A L U M I N U M / S T E E L		No Aluminum or Steel siding magazine advertisements were recorded for first quarter, 2005.	

Builders rated performance for ***Aesthetics***, ***Easy to maintain***, ***Warranty***, and ***Durability*** as very good for aluminum/steel siding. Manufacturers most heavily promote ***Aesthetics*** in product brochures

Standardized scores (Z-scores)

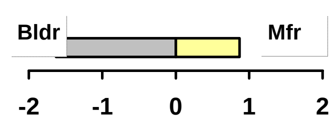
Builders rated attribute performance on a scale of -5 to +5 whereas manufacturer promotion is tallied using frequency of mentions in promotional text. For direct comparison of attributes in these databases, the Gap analysis uses standardized scores known as z-scores. Z-Scores essentially convert a scale or other score to a standard deviation. The z-score is the probability of something occurring, simply given a set of scores. For example, the builder z-score of -1.57 for *Durability* of wood composite siding means that *Durability* performance for wood composite siding was rated 1.57 standard deviations below the mean durability rating for all types of siding material. The builder performance z-score of +1.04 for fiber cement durability indicates that *Durability* was rated 1.04 standard deviations above the mean *Durability* for all types of siding. A negative z-score does not necessarily indicate an unfavorable rating, simply a rating that is less than the mean rating for all categories of siding for a given attribute. For example, the –1.57 builder z-score for *Durability* of wood composite siding results from the following data:

Mfr mean freq	Bldr mean -5 to +5		Manufacturer Z-score	Builder Z-score
1.40	1.00	wood comp	0.20	-1.57
2.69	3.50	solid wood	0.15	0.12
1.44	3.90	vinyl	0.02	0.40
0.64	5.00	brick	-0.36	1.18
1.72	4.80	fiber cement	-0.17	1.04
1.53	2.80	aluminum/steel	0.19	-0.33
0.71	2.00	stucco	-0.29	-0.59

Although wood composite siding's z-score of -1.57 is by far the lowest, builders rated wood composite siding's *Durability* performance as slightly better than neutral (1.00).

The z-scores only compare siding material categories for one attribute; they do not compare ratings or scores against other attributes. If builders rated *Durability* performance as very high for all types of siding, but there were slight deviations, then those would be reflected in the z-scores.

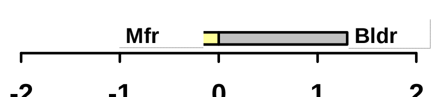
Large gaps, negative builder performance rating:



Larger gaps where builders rate an attribute less favorably and manufacturers promote that attribute more heavily indicate that manufacturers are aware of consumer perceptions and are using their promotional media to address a negatively perceived attribute. Thus, the large gap between builders' performance rating and manufacturer promotion for *Durability* of wood siding indicates that manufacturers are aware of and are addressing this performance issue.

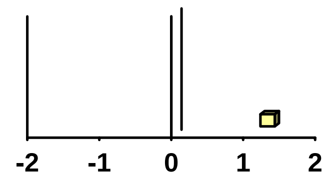
Large gaps, less frequently promoted by manufacturers:

Larger gaps where manufacturers promote an item less frequently and builders rate the performance of that item highly



could indicate that manufacturers recognize that consumers are already aware of the benefit of that attribute for their product (e.g., *Durability* for brick siding). It could also indicate an attribute that differentiates a product, suggesting that manufacturers should promote that attribute more often.

Small gaps:



Smaller gaps between manufacturer promotion and builder performance rating should be analyzed based on where they fall on the chart.

1) Close to neutral (y-axis) may indicate an area where manufacturers could address or promote an attribute more effectively.

2) High z-scores for both (right of y-axis) indicate that performance is in line with frequency of promotion as compared to other siding categories for this attribute. Manufacturers are promoting an attribute rated highly by builders.

3) Low z-scores for both (left of y-axis) indicate negative performance and low frequency of promotion. Manufacturers could address the perception of this attribute.

Gap Analysis by Attribute Charts:

The gap charts on the following pages compare z-scores from builder performance ratings to manufacturer promotional frequency. Line charts depicting builder performance ratings by siding material for each attribute are included, as well as line charts displaying combined promotional frequencies by siding manufacturers. The promotional frequencies represent a combination of the two databases developed in this study: 1) magazine advertisements and 2) product brochures (or Web pages when brochures were not available).

Gap Analysis by Feature

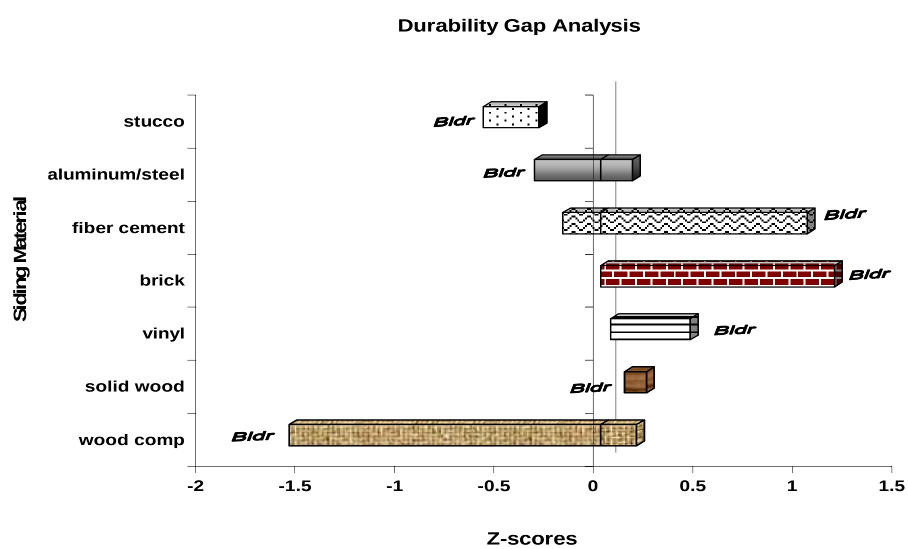
Durability

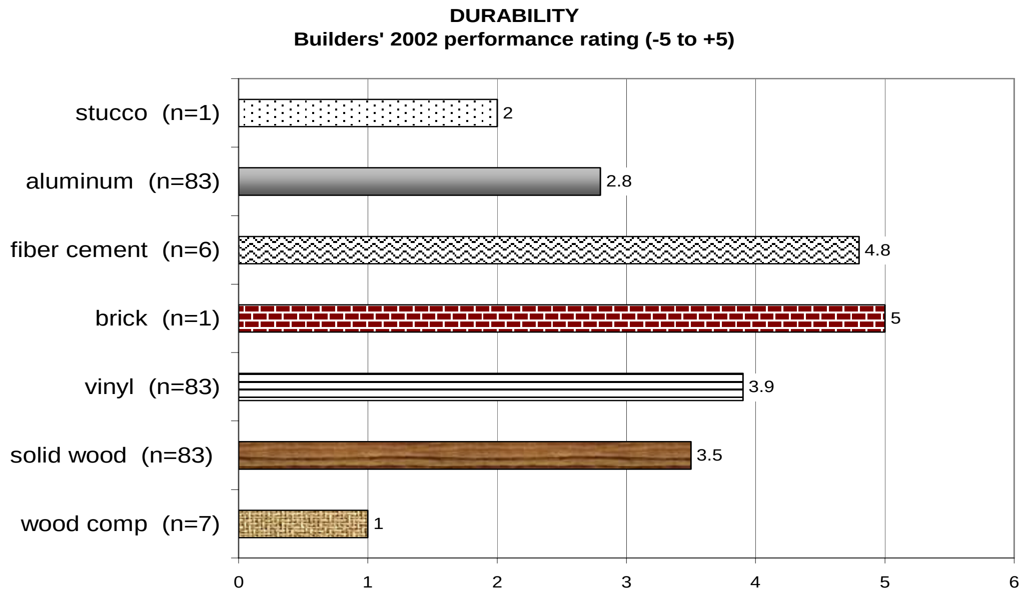
Builders rated *Durability* of brick and fiber cement sidings as highest, and rated wood composite durability as lowest (1.0 on a scale of -5 to +5). Manufacturers most often promoted *Durability* of solid wood, wood composite and aluminum/steel siding materials.

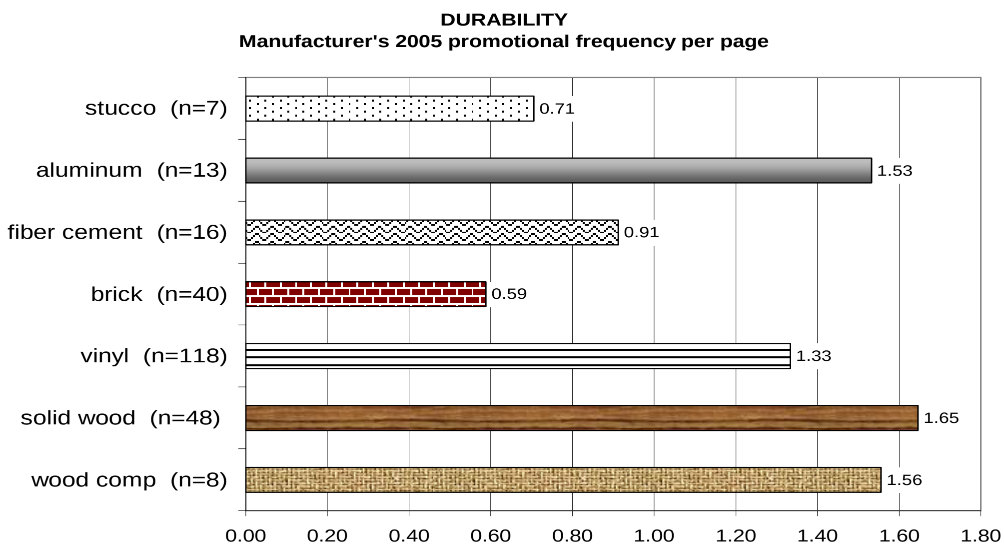
Gaps

Wood composite: Manufacturers are addressing the perception that *Durability* of wood composite siding is worse than for other types of siding material. Builders rate it as slightly better than neutral, but as less durable than other types of siding material.

Brick (n=1) and Fiber cement: *Durability* of Brick and Fiber Cement sidings is ranked as extremely high by builders but manufacturers don't capitalize on the durability attribute, promoting it least frequently for brick. Lack of promotion could be attributed to consumers' existing perceptions of brick and fiber cement as highly durable siding materials.




DURABILITY
Builders' 2002 performance rating (-5 to +5)
stucco (n=1)
aluminum (n=83)
fiber cement (n=6)
brick (n=1)
vinyl (n=83)
solid wood (n=83)
wood comp (n=7)
2
2.8
4.8
5
3.9
3.5
1
0
1
2
3
4
5
6


DURABILITY
Manufacturer's 2005 promotional frequency per page
stucco (n=7)
aluminum (n=13)
fiber cement (n=16)
brick (n=40)
vinyl (n=118)
solid wood (n=48)
wood comp (n=8)
0.71
1.53
0.91
0.59
1.33
1.65
1.56
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80

Easy to Install

Builders rated vinyl and fiber cement sidings as *easiest to install*, and rated brick and solid wood as most difficult to install. Manufacturers heavily promote wood composite siding as being easy to install.

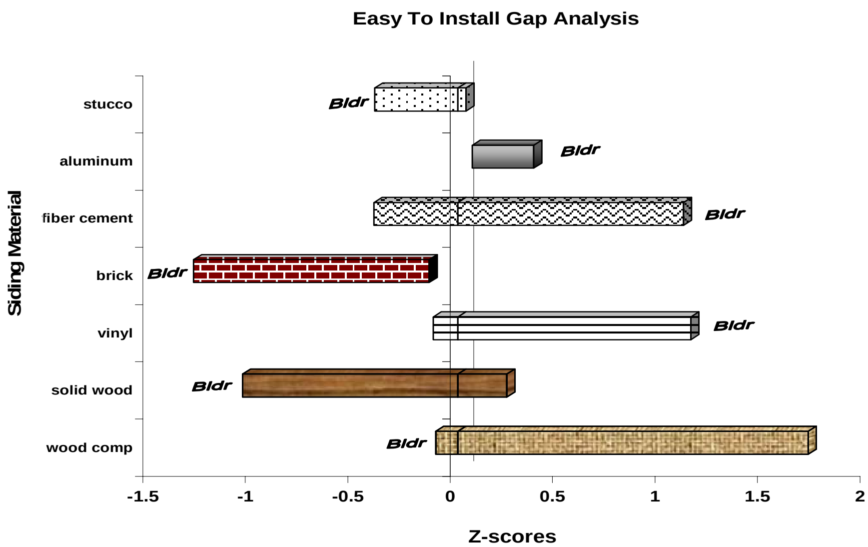
Gaps

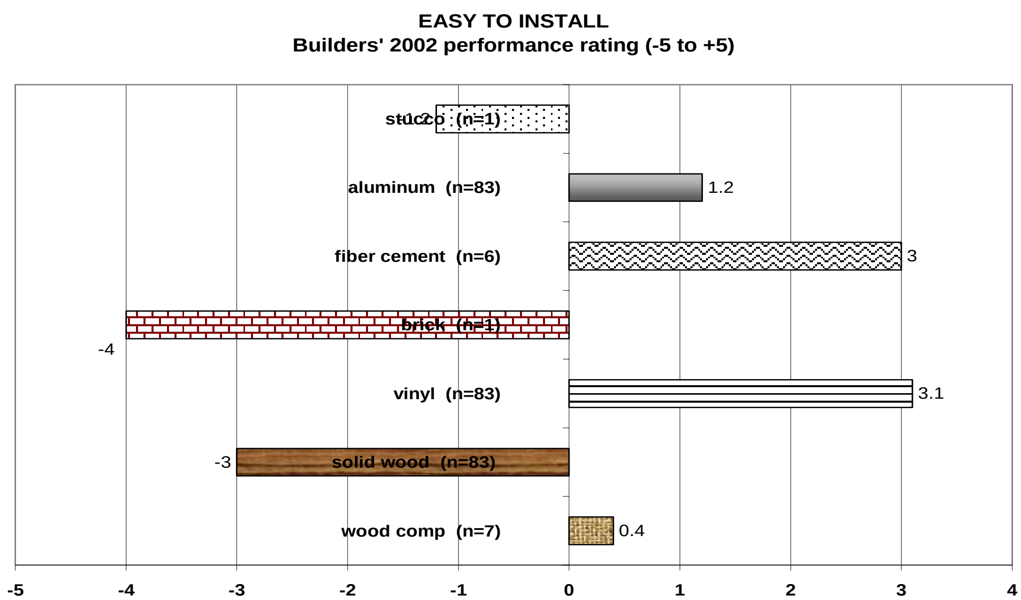
Wood composite: By frequently promoting *ease of installation*, manufacturers are addressing the perception that installation of wood composite siding is somewhat more difficult than for fiber cement, aluminum/steel and vinyl siding. Builders rank wood composite installation as just slightly better than neutral, but as easier to install than brick, solid wood or stucco. Manufacturers may be heavily promoting ease of installation for wood composite siding as an advantage over solid wood siding installation.

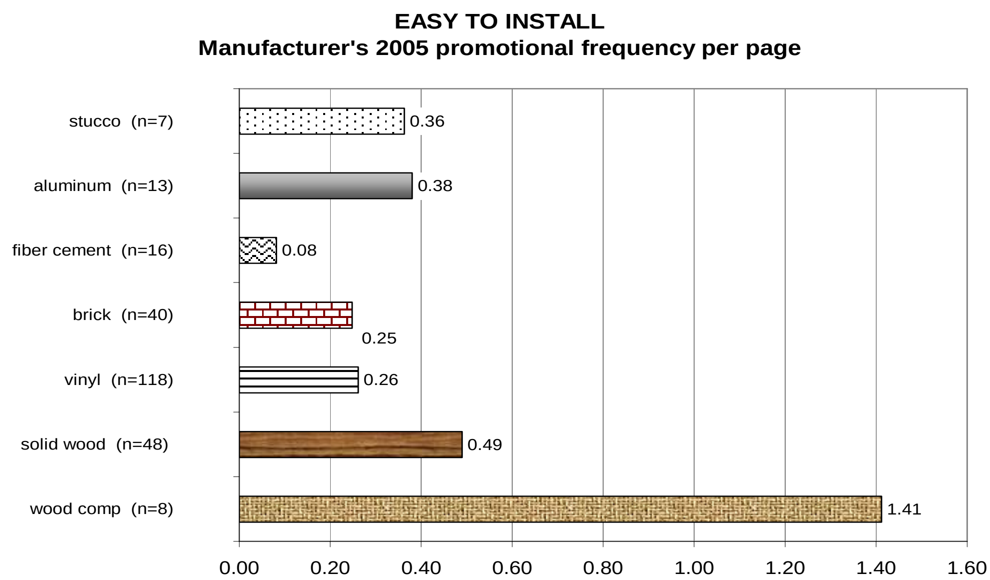
Solid wood: Manufacturers are also addressing the perception that installation of solid wood siding is more difficult than for other types of siding material. Builders rate installation of solid wood siding as more difficult than installation for any siding other than brick (n=1), suggesting that manufacturers could focus more on this issue.

Fiber cement and Vinyl: Builders consider fiber cement and vinyl sidings to be easy to install. Manufacturers under promote this feature/benefit.

Brick (n=1): Builders consider brick to be very difficult to install. Manufacturers infrequently promote this attribute for brick siding.


Easy To Install Gap Analysis
Siding Material
stucco
aluminum
fiber cement
brick
vinyl
solid wood
wood comp
Bldr
Bldr
Bldr
Bldr
Bldr
Bldr
Bldr
-1.5
-1
-0.5
0
0.5
1
1.5
2
Z-scores


EASY TO INSTALL
Builders' 2002 performance rating (-5 to +5)
stucco (n=1)
-1.2
aluminum (n=83)
1.2
fiber cement (n=6)
3
brick (n=1)
-4
vinyl (n=83)
3.1
solid wood (n=83)
-3
wood comp (n=7)
0.4
-5
-4
-3
-2
-1
0
1
2
3
4


EASY TO INSTALL
Manufacturer's 2005 promotional frequency per page
stucco (n=7)
aluminum (n=13)
fiber cement (n=16)
brick (n=40)
vinyl (n=118)
solid wood (n=48)
wood comp (n=8)
0.36
0.38
0.08
0.25
0.26
0.49
1.41
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60

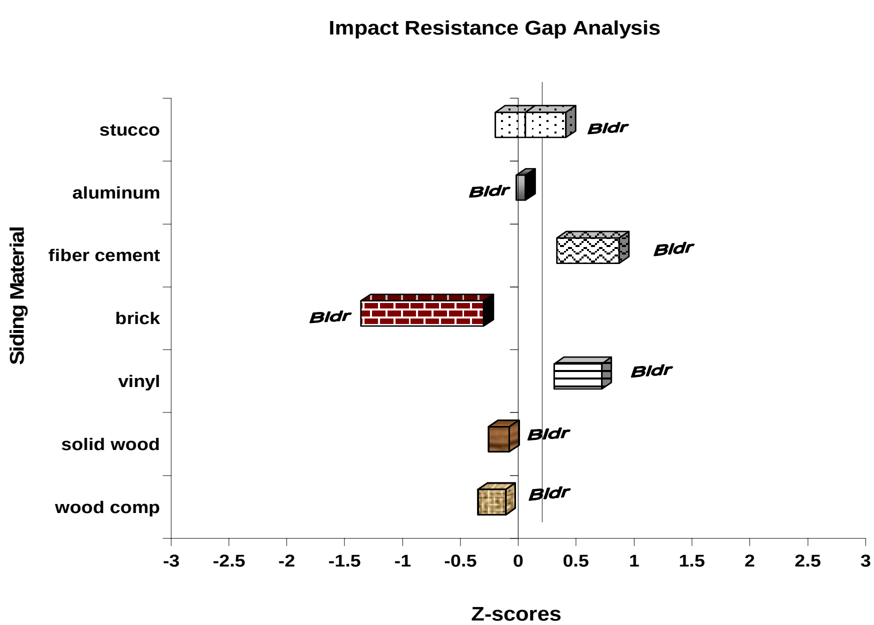
Impact Resistance

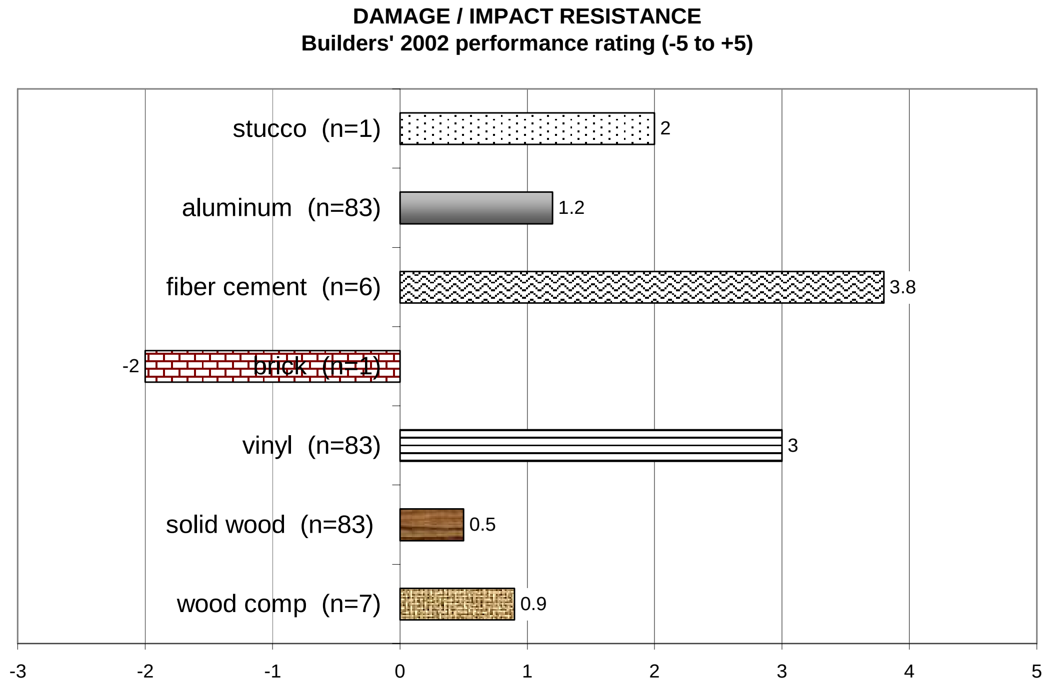
Builders consider fiber cement, vinyl and stucco sidings as most *damage/impact resistant*. Manufacturers heavily promote fiber cement, vinyl and aluminum/steel as being damage and impact resistant.

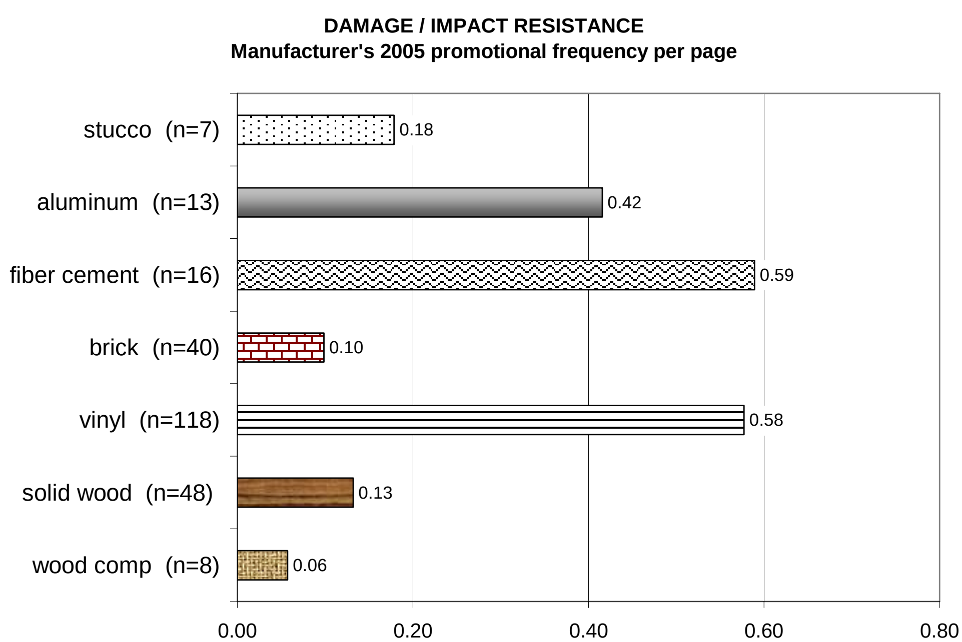
Gaps

Wood composite and Solid wood: *Impact/damage resistance* is rated by builders as only slightly better than neutral. Manufacturers don't promote *damage resistance* for wood composite and solid wood siding.

Fiber cement and Vinyl: Builders consider fiber cement and vinyl sidings to be highly resistant to damage/impact, more resistant than any other siding materials. Manufacturers are capitalizing on this by heavily promoting this attribute.




DAMAGE / IMPACT RESISTANCE
Builders' 2002 performance rating (-5 to +5)
stucco (n=1)
2
aluminum (n=83)
1.2
fiber cement (n=6)
3.8
brick (n=1)
-2
vinyl (n=83)
3
solid wood (n=83)
0.5
wood comp (n=7)
0.9
-3
-2
-1
0
1
2
3
4
5


DAMAGE / IMPACT RESISTANCE
Manufacturer's 2005 promotional frequency per page
stucco (n=7)
0.18
aluminum (n=13)
0.42
fiber cement (n=16)
0.59
brick (n=40)
0.10
vinyl (n=118)
0.58
solid wood (n=48)
0.13
wood comp (n=8)
0.06
0.00
0.20
0.40
0.60
0.80

Aesthetics

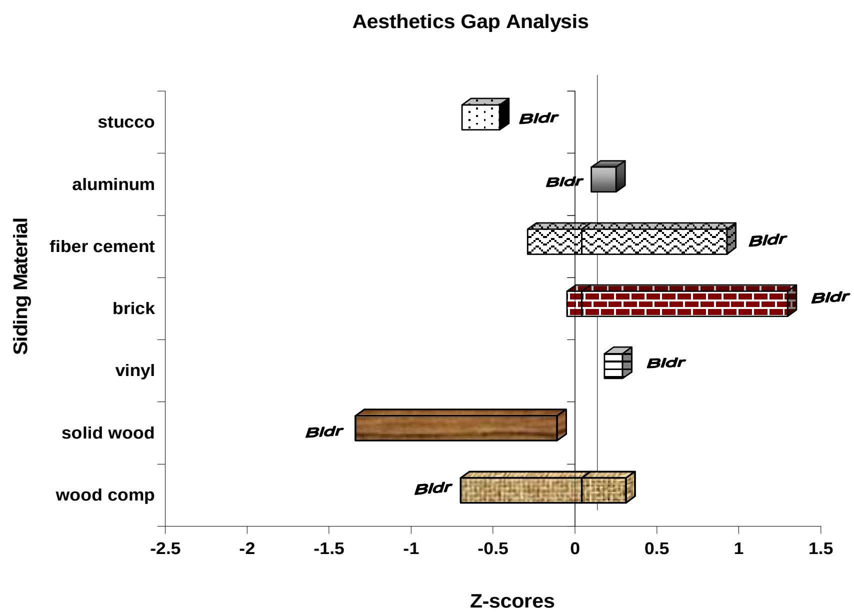
Aesthetics (curb appeal) was the most frequently promoted feature/benefit across all siding categories.

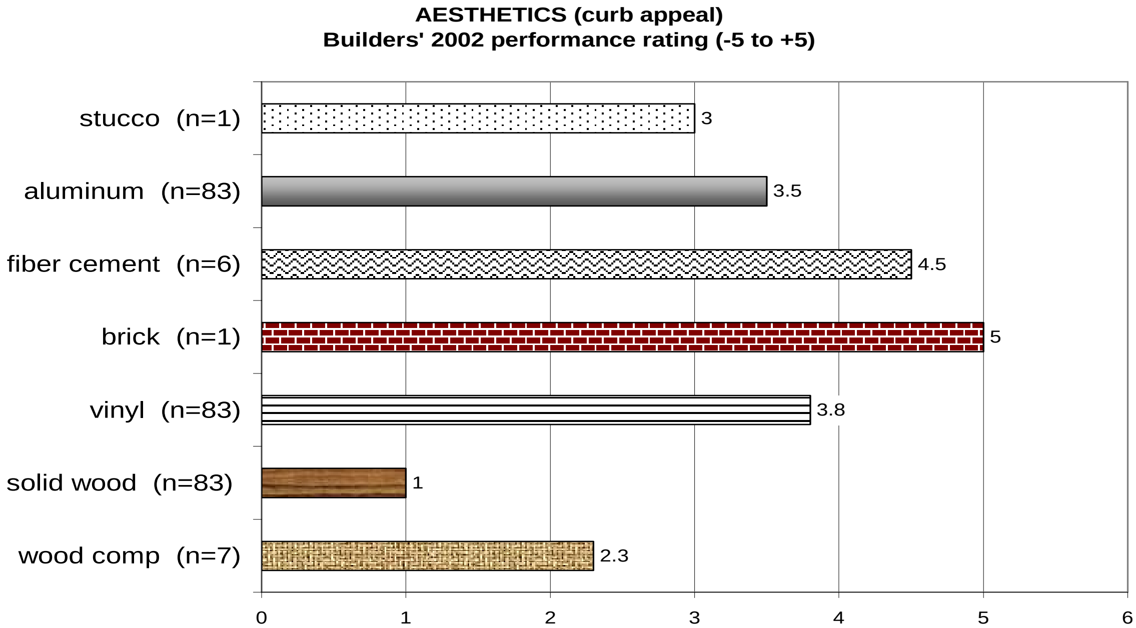
Gaps

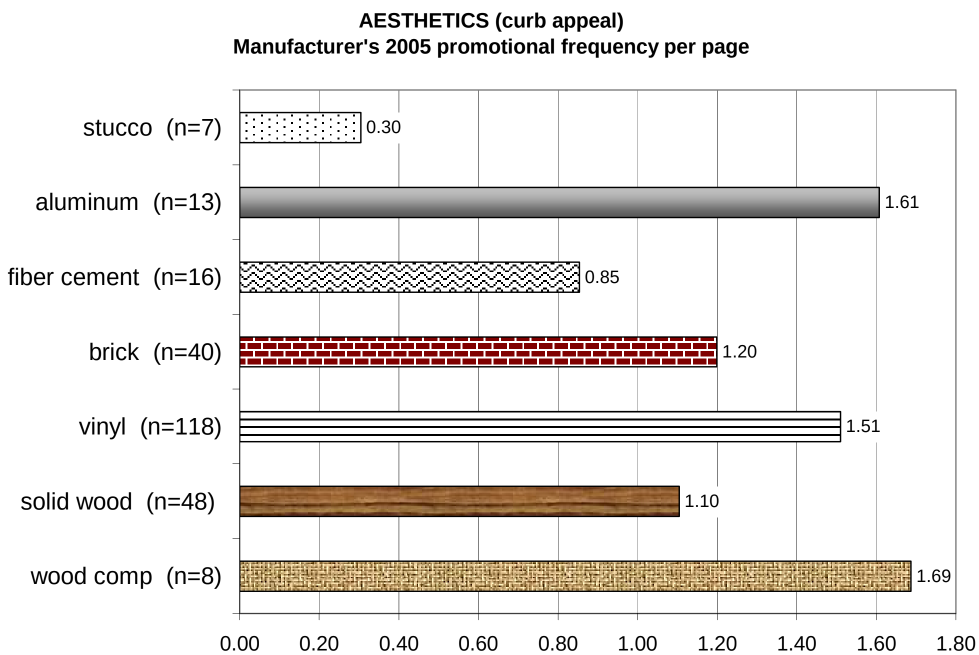
<u>Solid wood</u>: Builder rate *aesthetics* of solid wood siding as slightly better than neutral (1.0 on a -5 to +5 scale), but as lowest of all siding materials. Manufacturers promote *aesthetics* less for solid wood siding than for wood composite, vinyl, brick or aluminum. Manufacturers could better address/promote *aesthetics* of solid wood siding.

<u>Wood composite</u>: By promoting *aesthetics* more often for wood composite siding than for other siding materials, manufacturers are addressing the perception that wood composite siding has somewhat less curb appeal than other siding materials.

<u>Brick</u> (n=1) and <u>Fiber cement</u>: Builders rate *aesthetics* of brick and fiber cement as extremely high, but manufacturers don't promote this feature as often for brick and fiber cement as for wood composite, vinyl and aluminum sidings.




AESTHETICS (curb appeal)
Builders' 2002 performance rating (-5 to +5)
stucco (n=1)
aluminum (n=83)
fiber cement (n=6)
brick (n=1)
vinyl (n=83)
solid wood (n=83)
wood comp (n=7)
3
3.5
4.5
5
3.8
1
2.3
0
1
2
3
4
5
6


AESTHETICS (curb appeal)
Manufacturer's 2005 promotional frequency per page
stucco (n=7)
aluminum (n=13)
fiber cement (n=16)
brick (n=40)
vinyl (n=118)
solid wood (n=48)
wood comp (n=8)
0.30
1.61
0.85
1.20
1.51
1.10
1.69
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80

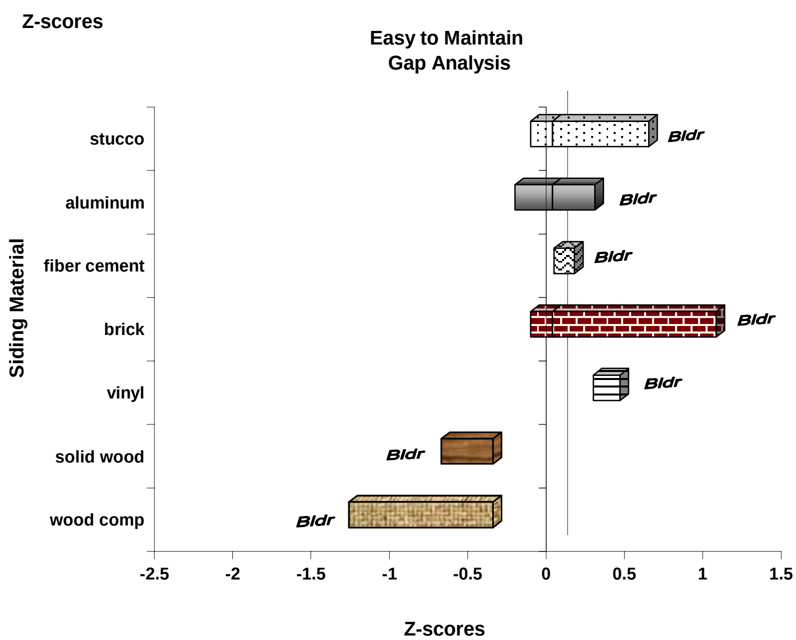
Easy to Maintain

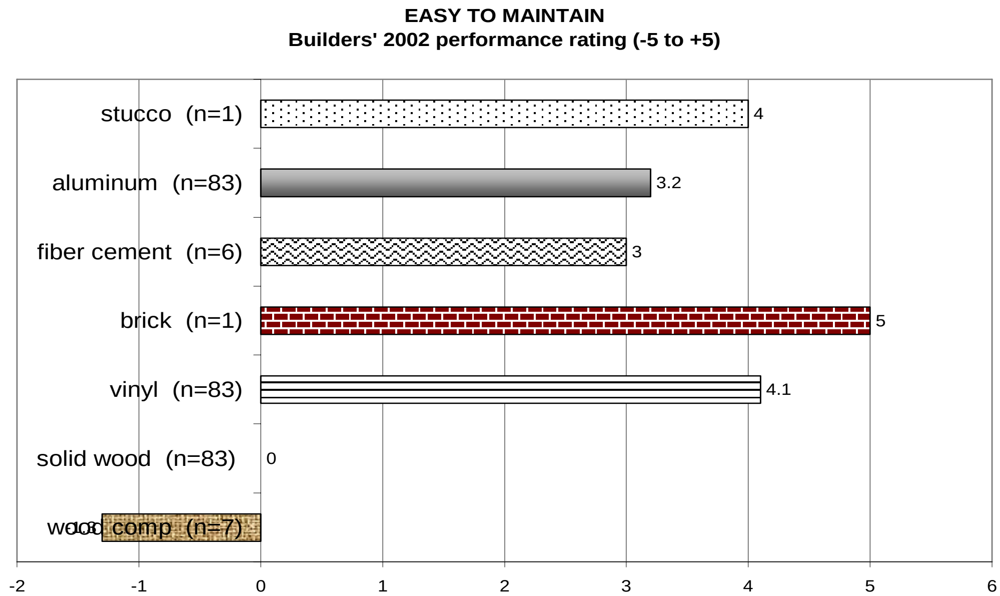
Builders rate wood composite and solid wood sidings as most difficult to maintain and rate brick, stucco and vinyl sidings as easy to maintain. Manufacturers most often promote low maintenance of vinyl siding.

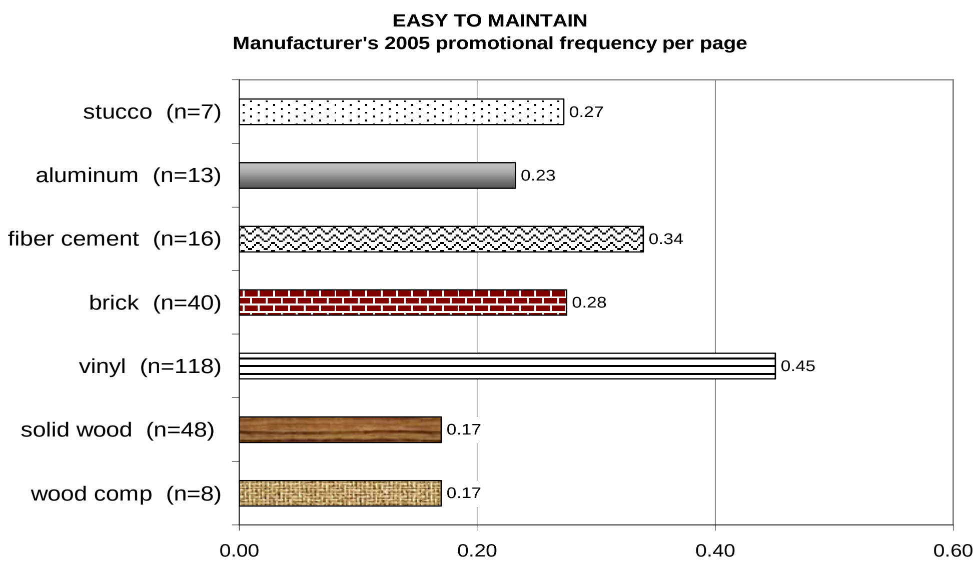
Gaps

<u>Wood composite</u>: Builders consider wood composite siding to be very difficult to maintain, more difficult than any other type of siding material. Manufacturers should address/promote *mantainability* of wood composite siding.

<u>Solid wood</u>: Builders rate solid wood siding as neutral in *ease of maintenance*. However, *ease of maintenance* of solid wood siding is not as positively rated as for all other siding materials other than wood composite. Manufacturers should address/promote *maintainbility* of solid wood siding.




EASY TO MAINTAIN
Builders' 2002 performance rating (-5 to +5)
stucco (n=1)
aluminum (n=83)
fiber cement (n=6)
brick (n=1)
vinyl (n=83)
solid wood (n=83)
wood comp (n=7)
4
3.2
3
5
4.1
0
-2
-1
0
1
2
3
4
5
6


EASY TO MAINTAIN
Manufacturer's 2005 promotional frequency per page
stucco (n=7)
aluminum (n=13)
fiber cement (n=16)
brick (n=40)
vinyl (n=118)
solid wood (n=48)
wood comp (n=8)
0.27
0.23
0.34
0.28
0.45
0.17
0.17
0.00
0.20
0.40
0.60

Quality

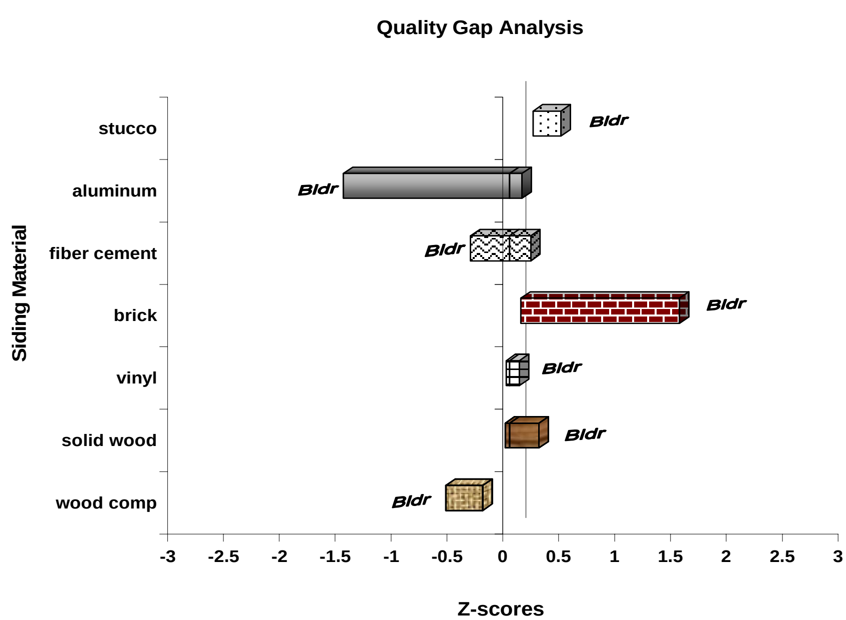
Brick and stucco sidings are rated by builders as having highest *quality* (status/image) of all siding materials, followed by solid wood and vinyl. Manufacturers most heavily promote the *quality* feature for stucco, fiber cement, aluminum/steel, and brick siding materials.

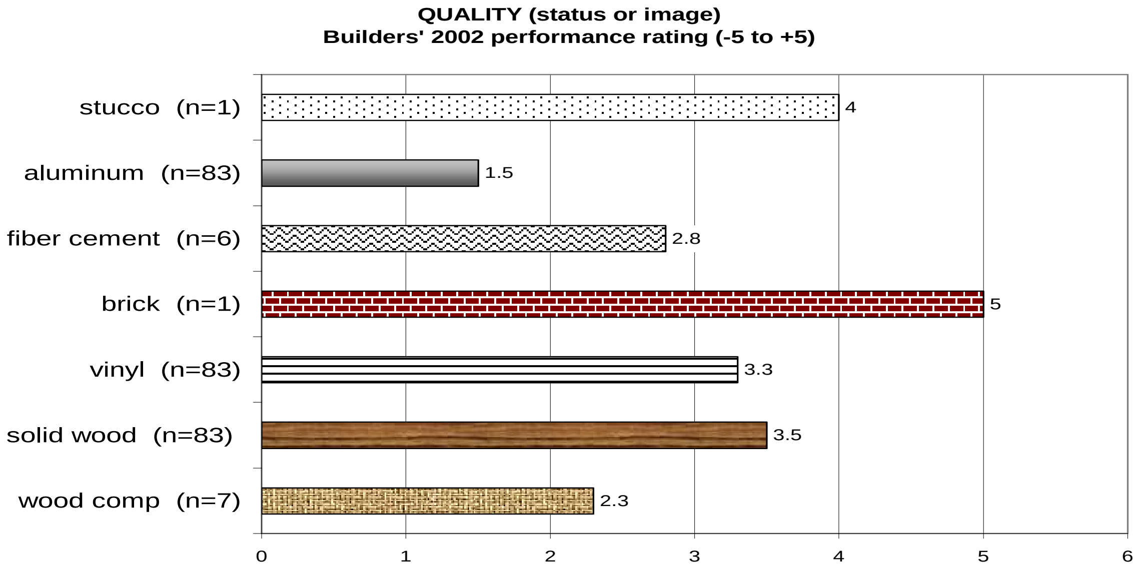
Gaps

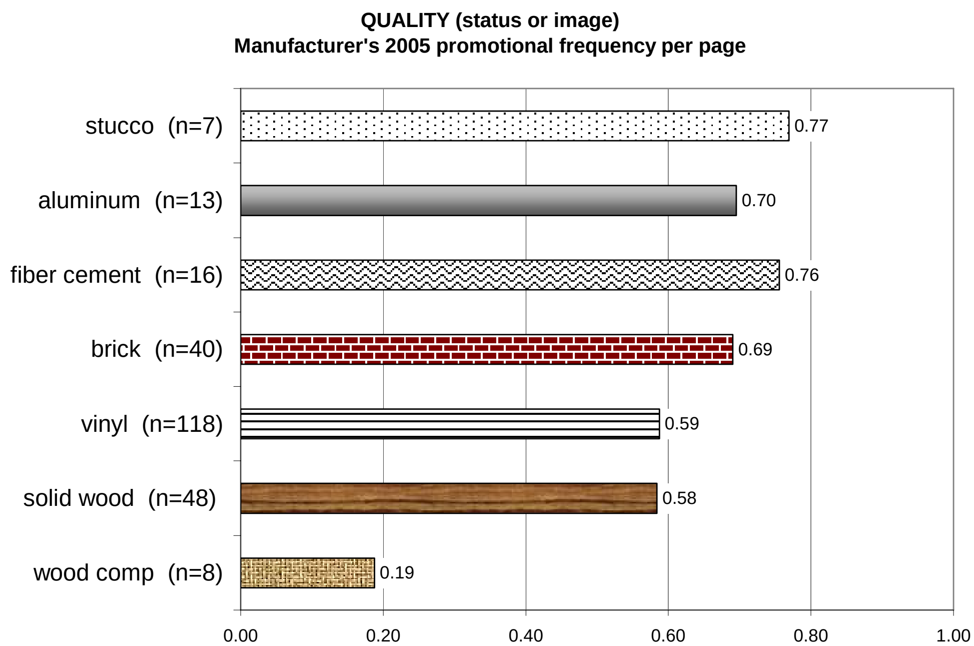
Aluminum/steel: Builders rate the *status/image* of aluminum/steel siding as lowest of all siding materials. Manufacturers should address and promote aluminum/steel siding's image.

Wood composite: Builders rate the *status/image* of wood composite siding as lowest after aluminum/steel. Manufacturers don't heavily promote the *quality/image* feature for wood composite siding.

Brick (n=1) : Builders rate the *status/image* of brick siding as highest of all siding materials. Manufacturers could capitalize on this perception by promoting this attribute more frequently.




QUALITY (status or image)
Builders' 2002 performance rating (-5 to +5)
stucco (n=1)
aluminum (n=83)
fiber cement (n=6)
brick (n=1)
vinyl (n=83)
solid wood (n=83)
wood comp (n=7)
4
1.5
2.8
5
3.3
3.5
2.3
0
1
2
3
4
5
6


QUALITY (status or image)
Manufacturer's 2005 promotional frequency per page
stucco (n=7)
aluminum (n=13)
fiber cement (n=16)
brick (n=40)
vinyl (n=118)
solid wood (n=48)
wood comp (n=8)
0.77
0.70
0.76
0.69
0.59
0.58
0.19
0.00
0.20
0.40
0.60
0.80
1.00

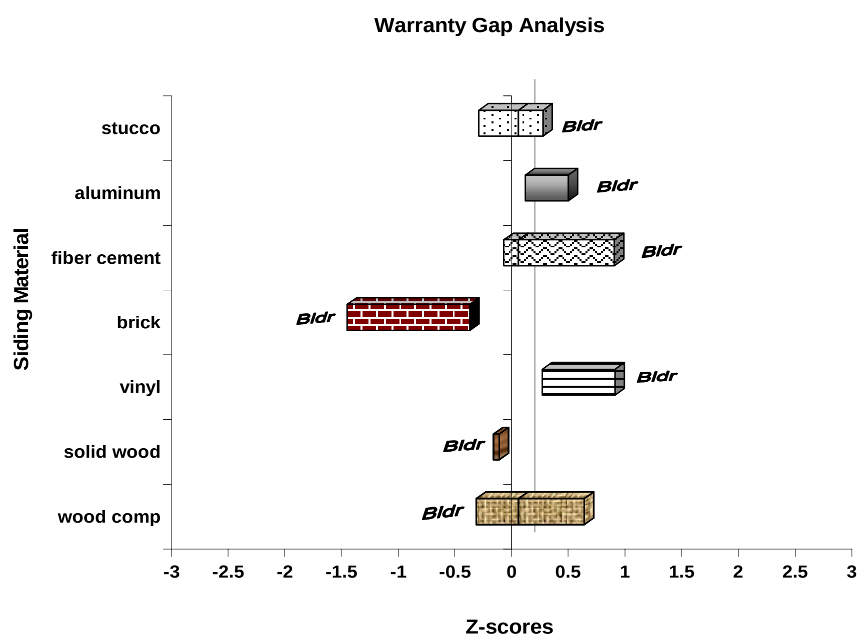
Warranty

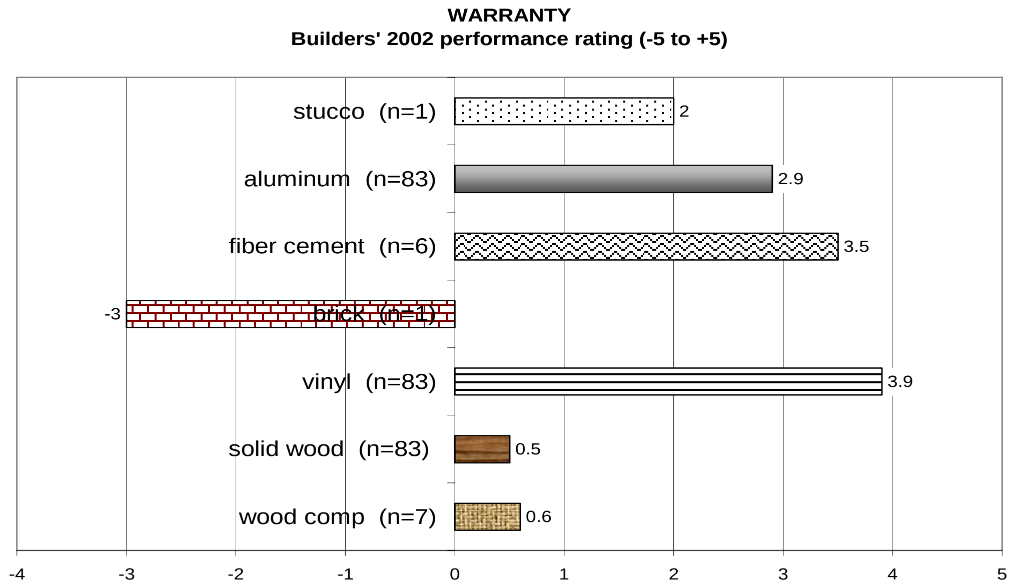
Manufacturers heavily promote *warranty* for wood composite siding, followed by aluminum/steel and vinyl. Builders rate warranty for vinyl, fiber cement, and aluminum/steel as very good.

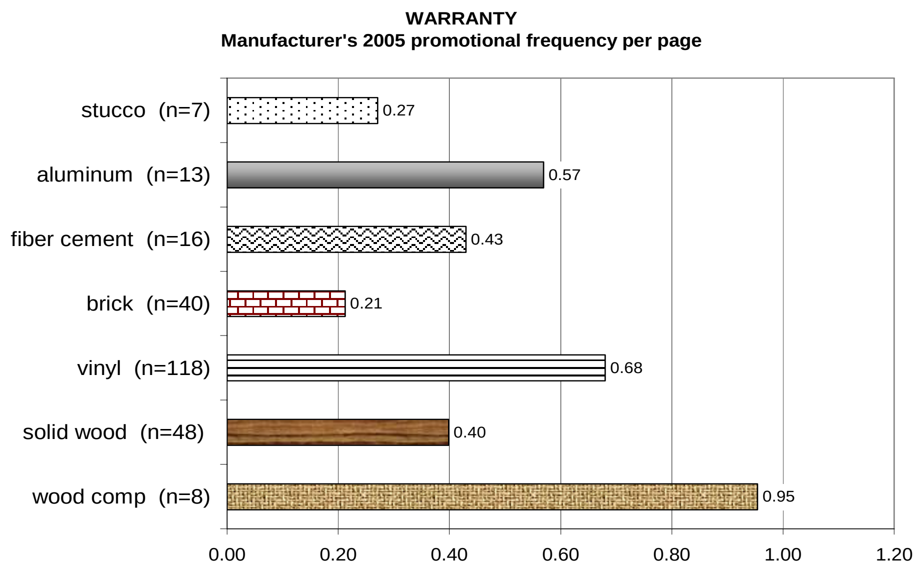
Gaps

Wood composite: Builders rate *warranty* for wood composite siding as slightly better than neutral. Manufacturers are focusing on changing this perception via their promotional materials.

Solid wood: Builders rate warranty for solid wood siding as slightly better than neutral. Manufacturers infrequently promote warranty for solid wood siding.




WARRANTY
Builders' 2002 performance rating (-5 to +5)
stucco (n=1)
aluminum (n=83)
fiber cement (n=6)
brick (n=1)
vinyl (n=83)
solid wood (n=83)
wood comp (n=7)
2
2.9
3.5
-3
3.9
0.5
0.6
-4
-3
-2
-1
0
1
2
3
4
5


WARRANTY
Manufacturer's 2005 promotional frequency per page
stucco (n=7)
aluminum (n=13)
fiber cement (n=16)
brick (n=40)
vinyl (n=118)
solid wood (n=48)
wood comp (n=8)
0.27
0.57
0.43
0.21
0.68
0.40
0.95
0.00
0.20
0.40
0.60
0.80
1.00
1.20

DISCUSSION

Limitations

- Smaller manufacturers do not have Web sites, may not have the resources to advertise in widely circulated magazines, and may not offer product brochures. Those manufacturers were not included in this study.
- Lack of mention of an attribute does not mean the manufacturer considers the attribute not to be important; i.e., ‘no mentions’ does not equal ‘not at all important’ or ‘extremely bad performance’. Certain manufacturers may attempt to differentiate a siding product by excessively promoting a particular attribute; for example, Boral Brick and Owens Corning heavily promote *Design Flexibility* for their brick and stone siding respectively, but most solid wood siding manufacturers advertise *Design Flexibility* little if at all. Moreover, builders were not asked to rate *Design Flexibility* in the 2002 study so these attributes can’t be compared.
- Manufacturers may choose to use advertising space to promote attributes that builders weren’t questioned about in the survey (e.g., *Technological savvy, Sound deadening/insulation, Certification/code approval, etc.* Reference Table 46).
- Omitting certain attributes, such as *Warranty*, might have negative impact; therefore, promotional items may include such attributes even if they aren’t considered to be of the ‘highest’ importance.
- Attributes promoted in graphics were not identified for the manufacturer promotion study. Graphics may be used to portray curb appeal (aesthetics), variety of styles, warranty seals, and other features.
- Variation of font style used for text strings was not considered in the text analysis of manufacturer promotion. For example, bold or italicized text may indicate higher promotional importance to the manufacturer.
- In terms of the manufacturer literature coding analysis, coding text has the possibility for numerous interpretations and therefore is subject to coding bias. Precautions were taken to reduce rater bias by having other raters examine the textual coding and test agreement.
- A second limitation with the manufacturer literature coding analysis is the assumption that the frequency of promoted product attributes represents the importance that manufacturers place on these attributes. Even though the logic of frequency of promotion representing attribute importance is persuasive, other explanations (e.g., that manufacturers promote what they think customers want to hear although they do not consider the attribute to be important) cannot be ruled out.
- Another assumption of this work is that the builder ratings of siding product attributes are comparable to the manufacturer promotional frequency.

Future Research

- Additional analysis of advertising rates as they relate to ad size, magazine, brand, type of siding material.
- Cluster analysis of promotional attributes to produce a smaller set of attributes. Various attributes may be combined, such as weather resistant, temperature resistant, sun/UV resistant, moisture resistant, etc.
- Market research of Paintability component.

CONCLUSIONS

This study analyzed 30 attributes promoted by U.S. residential siding manufacturers. Attributes were further examined within 8 siding material classifications. Gap analyses compared builder performance ratings to promotional frequency by siding material, as well as promotional strategies between magazine advertising and product brochures / Web pages. Overall, siding manufacturers convey the general message to builders that their products have curb appeal, can be incorporated into a multitude of home designs, have high quality, image or status, and are backed by a reputable company and product warranty.

Examination of promotional attributes by siding material classification suggests unique strategies. Different siding materials have distinct features and attributes. Knowledge about these attributes and the competitive advantage of each type of product is the basis of consumer product selection. *Design flexibility* and *Aesthetics* are key product attributes for all types of residential siding. *Design flexibility*, the ability of a siding material to be incorporated within numerous architectural styles, housing designs and siding layout schemes, appears at least once in 75% (188 of 250) of all promotional items. *Aesthetics* is also heavily promoted for all siding products (66.7%). In addition to *Design flexibility* and *Aesthetics*, manufacturers promote particular features within each material classification. Wood composite is the only group that does not frequently promote *Quality*. Solid wood, Wood composite and Steel don't promote *Company/product reputation* as frequently as other classifications.

Solid wood:	Cost effectiveness, Quality
Wood composite:	Easy to install, Warranty, Cost effectiveness
Vinyl:	Warranty, Quality, Reputation
Brick / masonry:	Reputation, Quality, Cost effectiveness
Fiber cement:	Reputation, Quality, Full product line, Cost effectiveness
Stucco:	Reputation, Quality, Product integrity
Aluminum:	Quality, Reputation
Steel:	Quality, Strength, Code approval/certification

Results of gap analyses of promotional frequency versus builder performance ratings further suggest unique promotional strategies. For example, builders' poor performance rating for *Ease of installation* for solid wood siding would suggest that manufacturers should address and/or promote installation features. Similarly, the *Easy to maintain* feature was seldom promoted by wood composite siding manufacturers and was rated as a poor performance

attribute by builders. A smaller gap indicated that wood composite manufacturers are addressing the perception that *Durability* of wood composite siding is worse than for other types of siding material.

Study implications should be helpful to manufacturers seeking to effectively position siding products within the marketplace and to researchers who wish to understand the nature of promotion within the residential siding industry.

ACKNOWLEDGEMENTS

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APPENDICES

APPENDIX A - LIST of MANUFACTURERS and BRANDS STUDIED

These 7 siding manufacturers were found in

magazine ads only (of 19 manufacturers)

Manufacturer name
Architectural Products by Outwater
Bear Creek Lumber
California Redwood Association
McGee Lumber
Michigan Prestain
Tapco
Western Red Cedar Association

These 12 siding manufacturers are in **both**
Web page / brochures and magazine ad databases

Manufacturer name
Boral Brick
Certainteed
Crane
Eldorado Stone
Granville Manufacturing Company
Hanson Brick
James Hardie
Louisiana-Pacific
Maibec
Owens Corning
Royal Group Technologies
Ward Clapboard Mill

APPENDIX A - LIST of MANUFACTURERS and BRANDS STUDIED

These 80 siding manufacturers are in the Brochure/Web database only (of 92 manufacturers)

Acme Brick	Henry Brick Co.	Resource Materials Corp.
Alcoa	Interfor	Robinson Brick Co.
Amcraft	International Steel	Rollex Corp.
Associated Material	IXL Brick	Roseburg Forest Products
Belden	Jenkins Brick Co.	Shakertown
Border Steel	Kaycan	St. Joe Brick Works, Inc.
Bowerston Shale	Kluckwan, Inc.	Styles & Hart Brick Co.
Brampton Brick	LaHabra Stucco	Summit Brick & Tile Co.
California Stucco	Lawerenceville Brick	Taylor Clay Products Co.
Canadian Forest Products	Lee brick	Teal Cedar Products Ltd.
Carolina Ceramics	Merlex Stucco	Temple
Cedar Valley, Inc.	Mitten Vinyl Siding	Texas EIFs
Cedarsource	Monolite Stucco	The Foundry
Collins Manufacturing	Nailite	The McAvoy Brick Co.
Columbia Cedar Inc.	Nichiha	The Shaw Group Ltd.
Columbus Brick	Norandex	Triangle Brick Co.
Dryvit	Northwest Forest Prod.	Twin Rivers Cedar Prod.
Elder Forest Products	Nucor	Tyee Timber Products, Ltd.
EZ Rock	Pacific Clay Products	US Steel
Fabral	Pacific Wood Laminates	Variform
General Shale Brick, Inc.	Palco	Watsontown Brick Co.
Georgia Pacific Hardboard	Pine Hall Brick Co.	Welco USA/Skookum
Glen-Gery Corporation	Plum Creek	Westshore Specialties
Haida Forest Products	Potlatch Corporation	Weyerhauser
Heartland	Premier Forest Prod., Inc.	Wheeling Corrugating Co.
Hebron Brick	Quickrete	Woodtone Building Prods
	Redland Brick Inc.	Wynndel Box & Lumber

165 Unique Brands of Siding

1.	ABTCO	Certainteed	Lawerenceville Brick	Potlatch
2.	ABTCO-Hardboard	Channel Drain	Lee Brick	Premier Cedar
3.	Acme	Classic	LP Maxim	Quickrete
4.	Alcoa (Aluminum)	Collins True Wood	LP Smartside	Redland Brick
5.	Alcoa (Vinyl)	Colonial Beaded	Maibec	Residential
6.	Alside Architectural Classics	Columbia Cedar	Main Street	RMC
7.	Alside Board & Batten	Columbus Brick	Mastic	Robinson Brick
8.	Alside Centerlock	Craneboard	Maxim	Rollex (steel)
9.	Alside Charter Oak Energy Elite	Dakota	McAvoy Brick	Rollex Aluminum
10.	Alside Charter Oak Ultimate	Designer Shake Hand Split	McGee	Rollex Vinyl
11.	Alside Conquest	Designer Shake Rough Sawn	Merlex	Roseburg
12.	Alside Landscape	Dryvit	Michigan Prestain	Royal
13.	Alside Odyssey Plus	Durabuilt	Millenium	Shakertown
14.	Alside Pelican Bay Hand Split	Duraplank	Mitten	Shaw Brick
15.	Alside Pelican Bay Shakes	Elder Forest Products	Monogram	Skookum Cedar
16.	Alside Seneca	Eldorado Stone	Monolite	St. Joe Brick
17.	Alside Steel	EZRock	Nailite	Styles & Hart Brick
18.	Alside Williamsport	Fabral	Napco Aluminmum	Summit Brick
19.	Amcraft	General Shale	Napco American 76 Beaded	Taylor Brick
20.	Architectural	Gentek	Napco American Comfort	Teal Cedar
21.	Ashton Heights	Georgia Pacific	Napco American Heritage	Temple
22.	Bear Creek	Georgia-Pacific Vinyl	Napco American Splendor	Texas EIFs
23.	Belden	Glen-Gery	Napco American Splendor XL	The Foundry
24.	Board & Batten (Royal)	Granville	Napco American Tradition	Timber oak
25.	Boral Brick	Haida	Nichiha	Triangle Brick
26.	Border Steel	Hamilton	Norandex	True Comfort
27.	Bowerston	Hanson Brick	Norman Rockwell	Twin Rivers Cedar
28.	Brampton Brick	Heartland	Northern Star	Tyee Cedar
29.	California Redwood	Hebron Brick	Northwest Cedar	USS
30.	California Stucco	Henry Brick	Nostalgia Series	Variform
31.	Camden Pointe	Hudson Bay	Nottingham	Varigrain Preferred
32.	CANFOR	Interfor Cedar	Nucor Building Systems	Vinyl Carpentry
33.	Carolina Beaded	ISTG	Outwater	Vytec
34.	Carolina Brick	IXL Brick	Owens Corning (stone)	Ward Clapboard Mill
35.	Cedar Impressions	James Hardie	Owens Corning (vinyl)	Watsontown Brick
36.	Cedar One	Jenkins Brick	Pacific Clay	Weatherboards
37.	Cedar Series	Journeymen Laminates	Pacific Wood Laminates	Western Red Cedar
38.	Cedar Valley	Kaycan (vinyl)	Palco	Westshore Cedar
39.	Cedarsource	Kaycan Aluminum	PastelCote	Woodland
40.	Cellwood	K-Ply	Pine Hall Brick	Woodtone
41.	Cemplank	LaHabra	Plum Creek	Wyndell
42.	Century Drain			

APPENDIX A - LIST of MANUFACTURERS and BRANDS STUDIED

Manufacturers / Multiple brands of siding included

Manufacturer	*Brands Advertised*	# cases	Percent
Variform	Ashton Heights Camden Pointe Durabuilt Georgia-Pacific Vinyl Napco Aluminum Napco American 76 Beaded Napco American Comfort Napco American Heritage Napco American Splendor Napco American Splendor XL Napco American Tradition Nostalgia Series Nottingham Timber oak Variform (2) Varigrain Preferred	17	10.6
Associated Materials	Alside Alside Architectural Classics Alside Board & Batten Alside Centerlock Alside Charter Oak Energy Elite Alside Charter Oak Ultimate Alside Conquest Alside Landscape Alside Odyssey Plus Alside Pelican Bay Hand Split Shakes Alside Pelican Bay Shakes Alside Seneca Alside Steel Alside Williamsport Gentek	15	9.4
Certainteed	Carolina Beaded Cedar Impressions Certainteed Classic Hamilton Main Street Millenium Monogram True Comfort Vinyl Carpentry Weatherboards (2)	12	7.5

Manufacturer	*Brands Advertised*	# cases	Percent
Royal Building Products	Architectural Board & Batten Cedar Series Colonial Beaded Designer Shake Hand Split Designer Shake Rough Sawn Duraplank Journeymen Journeymen Laminates Residential Royal Building Products Woodland	12	7.5
Louisiana-Pacific	ABTCO-Hardboard ABTCO Dakota Hudson Bay LP Smartside Maxim Norman Rockwell Northern Star	8	5.0
Alcoa	Alcoa Siding (2) Cellwood Mastic	4	2.5
James Hardie	Cemplank James Hardie	2	1.3
Kaycan	Kaycan Kaycan Aluminum	2	1.3
Owens Corning	Owens-Corning Vytec	2	1.3
Rollex Corporation	Rollex Aluminum Rollex Steel Rollex Vinyl	3	1.3
Wheeling Corrugating Co.	Century Drain Channel Drain	2 79	1.3

APPENDIX B – Brochure / Web Data Dictionary

Variables

Case - case number assigned to product brochures/Web page entries. Each siding brand is given a unique case number for tracking. The case numbers match the cases numbers in the NVivo files (numeric).

Manufacturer - This variable captures the manufacturer name. Note that some manufacturers are owned by parent companies in which case the parent company is listed as the manufacturer, and the Brand name field identifies the siding brand (Associated Materials owns Alside and Gentek). When 3rd party manufacturing occurs, e.g., Variform manufacturers Georgia-Pacific's vinyl siding, the manufacturer is listed in this field (e.g., Variform) and the Brand name field identifies the distributor (e.g., Georgia-Pacific vinyl) (text).

Manufacturer code - is an arbitrarily assigned code for each manufacturer that will identically match the manufacturers in the ad database and other future databases if created (numeric).

Siding material code - is a classification scheme used to aggregate similar cladding products into categories for analysis. Note that plywood siding is categorized as solid wood since it is an older technology and fits better with solid wood products than with engineered composites such as MDF or OSB (numeric).

1 = wood composite
2 = solid wood
3 = vinyl
4 = aluminum
5 = brick/masonry
6 = stucco
7 = fiber cement
8 = steel

Product - each siding product type is coded according to primary material used. Examples are cedar, redwood, brick, stone, steel, vinyl and wood composite. The text product descriptions are a refinement of the siding material code. For example, a data item may have material code of "2" (solid wood), but may have product type listed as cedar, cypress, redwood, or Douglas fir (text). Product text strings are:

aluminum	brick	cedar	cypress
Douglas fir	fiber cement	MDF	MDO
pine	redwood	steel	stone
stucco	vinyl	wood composite	

Brand - is the manufacturer brand name for the siding product; for most products it's the company name (text).

Brand number - is used to numerically code each brand since several manufacturers have multiple brands/products within the same material category. For example, Certainteed offers 10 vinyl products ranging from 'decorative shakes' to 'board and batten' (numeric).

Brochure Code - is either the Web site URL or an identifier for the piece of product literature. For printed brochures the code is typically listed on the back cover and for Web pages this is the company home page Web address (text).

Brochure Date - is the year published for printed literature or the year viewed for product web pages. (numeric – year only).

Source - identifies the product information source. If the information was pulled from the World Wide Web the field will be marked with a "1"; if printed literature was reviewed the field will be marked with a "0" (dichotomous).

Average page size - for each source reviewed, the page size was calculated in square inches. Printed literature was measured with a standard ruler and page sizes were recorded for each piece. The standard page size (8.5" x 11" or 93.5 sq in) was used for Internet product information since most Web pages are designed to print onto a single sheet of standard paper (numeric).

Number of pages - for each piece of product literature or product Web site reviewed, a page count was tallied (numeric).

Number of product types - the number of siding products promoted within each piece of manufacturer literature or within product Web pages. Products were categorized according to physical profile of form. Examples of common product forms are standard lap, Dutch lap, shake, decorative shake, panel, board & batten and stucco (numeric).

Percentage siding - the percentage of a piece of literature or Web pages dedicated to the siding product. When a manufacturer promoted multiple product categories within the same piece of literature (promoting a full product line), the percentage allocated to siding was estimated (percent).

Lap siding offered - determines if a manufacturer/brand offered a lap siding product, "1" = yes and "0" = no (dichotomous).

Wood siding offered - determines if a manufacturer/brand offered a wood grained (real or simulated) siding product, "1" = yes and "0" = no (dichotomous).

Dutch lap siding offered - determines if a manufacturer/brand offered a Dutch lap siding product"1" = yes and "0" = no (dichotomous).

Beaded lap offered - determines if a manufacturer/brand offered a beaded lap siding product, "1" = yes and "0" = no (dichotomous).

Board & batten offered - determines if a manufacturer/brand offered a board & batten siding product, "1" = yes and "0" = no (dichotomous).

Shakes offered - determines if a manufacturer/brand offered a shake siding product, "1" = yes and "0" = no (dichotomous).

Decorative shakes offered - determines if a manufacturer/brand offered a decorative shake siding product (e.g., ½ rounds or fish scales, etc.), "1" = yes and "0" = no (dichotomous).

Panel offered - determines if a manufacturer/brand offered a panel siding product (usually in 4'x8' dimension), "1" = yes and "0" = no (dichotomous).

Stucco surface offered - determines if a manufacturer/brand offered a stucco siding product, "1" = yes and "0" = no (dichotomous).

Median number of colors - The median number of colors offered were calculated for each piece of brochure/ web pages reviewed to determine the range of colors offered by manufacturers.

Pre-finish offered - this variable determines if a manufacturer offered a pre-finished siding product, "1" represents yes and "0" represents no. Products like vinyl are prefinished by their nature and were marked accordingly whereas solid wood siding manufacturers may or may not offer this feature (dichotomous).

Finish warranty - if numeric value is present, it represents the number of years the manufacturer offered a finish warranty (numeric).

Product Warranty - if numeric value is present, it represents the number of years the manufacturer offered a product warranty (numeric).

Product Attribute section

The next series of variables represent textual counts or number or references of product attribute categories for manufacturer siding brochures or product web pages.

Aesthetics - Count of aesthetically pleasing attributes mentioned within a piece of product promotion brochures or web pages. Terms such as *beauty* or *curb appeal* were coded into the aesthetic category (numeric).

Availability - This category refers to manufacturer statements of products being easily obtained in the market such as *convenient distribution* or *ease of sourcing* (numeric).

Code approval/certification - This category captured the number of third party references from manufacturers that bolstered the presentation of their products. Text referencing legitimate third parties such as *ASTM, Good Housekeeping, ISO 9000, association approved* or *building code approval* were tallied in this category (numeric).

Corrosion resistance - Count of text references to the corrosion resistant nature of a product such as *no chalking, rust resistant* or *corrosion resistant* (numeric).

Cost effectiveness - Count of text references to the economics of a product such as *adding value to a home, saving money* or any type of cost based rhetoric (numeric).

Customer service - Count of any references to *customer service* as a benefit (numeric).

Deadens sound - Count of references to sound insulating properties of siding materials such as *reduces outside noise* and other references to sound reducing properties (numeric).

Design flexibility - Count of references that infer design flexibility such as a *full array of colors, styles* and *textures*. In addition references to product or look variety were also captured as design flexibility (numeric).

Dimensional stability - Count of references that infer that the product doesn't change shape or size. Dimensional stability can be challenged by temperature change (mostly vinyl) or changes in moisture (wood products) (numeric).

Durability - Count of references to product durability such as *lasts a long time* or the product is *extremely durable* (numeric).

Ease of installation - This variable captures all references that imply that the product is easier to install, use or handle during the construction process (numeric).

Ease of maintenance - Captures all references for low product maintenance such as no cleaning needed or painting needed (numeric).

Energy efficiency - This category captures all references to energy efficiency or savings as a result of using a siding products including stabilizing temperature changes within a structure or insulating properties (numeric).

<u>Performance under extreme circumstances</u> - This category captures all references to a siding product holding up to extreme events of natures such as fire, hurricanes and earthquakes (numeric).

<u>Environmental friendliness</u> - This category captures any references to the “greenness” of a product or environmental benefits a product provides such as less waste or sustainable harvest (numeric).

<u>Full product line offered</u> - This category captures all references to manufacturers offering a full line of products that can be additional siding materials or other exterior accents such as trim, windows, etc. (numeric).

<u>Impact resistance</u> - This category captures all references to a siding material’s impact resistance from outdoor items or weather events such as hail (numeric).

<u>Insect and mold resistance</u> - This category captures all references to pests that could potentially damage a siding product such as ants, termites, mold and decay fungi (numeric).

<u>Moisture resistance</u> -This category captures manufacturer promotion of a siding product’s moisture resistant features. Text references such as rain resistance, moisture barrier would be included in this category (numeric).

<u>Non-toxic</u> - This variable captures textual references of product non-toxicity. Text references such as inert, or no harmful by products would be included in this category (numeric).

<u>Product integrity</u> – This category refers to manufacturer statements that reflect the consistency or soundness of their products such as finest raw materials or product consistency (numeric).

<u>Strength</u> - This variable captures manufacturer references to products strength. Text examples included in this category include product rigidity, strength or toughness (numeric).

<u>Quality attribute</u> - This variable captures quality references by siding manufacturers across all facets of their operations from products quality to quality control in operations.

<u>Sound company/product reputation</u> - This variable captures manufacturer references that are intended to bolster their company or the product’s reputation. Examples are history in business and wide builder/consumer acceptance or recognition of the product or company.

<u>Sun/ultra-violet/fade resistance</u> - This variable measures the amount of manufacturer text entries that were categorized as reflective sun (fade) resistant properties. Textual references such as ultra-violet protected and holds up to the sun were entered into this category (numeric).

<u>Technologically savvy</u> - This category captures manufacturer references to technology either as a company or as used to manufacture, develop or support product delivery. Also references such as innovative or state-of-the-art are included in the category (numeric).

<u>Temperature resistance</u> - This variable represents manufacturer text entries that reflect product resistance to temperature changes or performance in extreme temperature conditions (numeric).

<u>Warranty</u> - The warranty category captures all text that specifically mentioned product warranties which included both substrate and finish warranty text (numeric).

<u>Weather resistance</u> - This variable includes all manufacturer text that references product weather resistance either using weather in the text or motioning resistance against Mother Nature or the elements (numeric).

Wind resistance - The wind resistance category captures all manufacturer text references to products withstanding wind loads. Text that refereed to wind test results or hurricane wind resistance were included in this category (numeric).

APPENDIX C – Magazine Advertisement Data Dictionary

Variables

Case - case number assigned to product brochures/Web page entries. Each siding brand is given a unique case number for tracking. The case numbers match the cases numbers in the NVivo files (numeric).

Manufacturer - This variable captures the manufacturer name. Note that some manufacturers are owned by parent companies in which case the parent company is listed as the manufacturer, and the Brand name field identifies the siding brand (Associated Materials owns Alside and Gentek). When 3rd party manufacturing occurs, e.g., Variform manufacturers Georgia-Pacific's vinyl siding, the manufacturer is listed in this field (e.g., Variform) and the Brand name field identifies the distributor (e.g., Georgia-Pacific vinyl) (text).

Manufacturer code - is an arbitrarily assigned code for each manufacturer that will identically match the manufacturers in the ad database and other future databases if created (numeric).

Siding material code - is a classification scheme used to aggregate similar cladding products into categories for analysis. Note that plywood siding is categorized as solid wood since it is an older technology and fits better with solid wood products than with engineered composites such as MDF or OSB (numeric).

1 = wood composite
2 = solid wood
3 = vinyl
4 = aluminum (in Web page/lit, but none in ad database)
5 = brick/masonry
6 = stucco (in Web page/lit, but none in ad database)
7 = fiber cement
8 = steel (in Web page/lit, but none in ad database)

Product - each siding product type is coded according to primary material used. The text product descriptions are a refinement of the siding material code (text). Product text strings included are:

brick, fiber cement, solid wood, stone, vinyl, wood composite

Brand - is the manufacturer brand name for the siding product; for most products it's the company name (text).

Brand number - is used to numerically code each brand since several manufacturers have multiple brands/products within the same material category. For example, Certainteed offers 10 vinyl products ranging from 'decorative shakes' to 'board and batten' (numeric).

Magazine – the magazine name (text). Magazines included were:

Magazine
Builder
Professional Builder
Fine Homebuilding
Remodeler
Journal of Light Construction
Professional Remodeler

Magazine code - Trade magazines reviewed were each assigned a review code (numeric).

> Builder Magazine = 1, Professional Builder = 2, Fine Homebuilding = 3, Remodeler = 4, Journal of Light Construction = 5, Professional Remodeler = 6

Volume - an annual identifying number assigned by the publisher to the trade magazine; for example, the January *Builder* magazine is volume 28 (numeric).

Issue - the magazine's issue number; for example, the January *Builder* magazine issue number is 1 (numeric).

Page no - the page number where the ad is located. If there is more than one ad for a manufacturer each ad is entered separately (numeric).

Ad size – total square inches of space dedicated to the advertisement (numeric).

Layout - Lists the ad's page consumption percentage: full page = 100, ½ page =50, 1/3 page = 33, ¼ page =25, & 1/8 =12.5 etc (numeric).

HorVer - refers to the ad positioning: horizontal = 0 or vertical = 1 (dichotomous).

Bleed - refers to edge bleed - bleed =1 or no bleed= 0 (dichotomous).

Loc - refers to select locations: front cover =1, back cover = 2, Inside front = 3 and Inside back =4 (numeric).

Rate - refers to the rate paid (in U.S. dollars) for the ad according to the magazine's 2005 rate card (numeric).

Ad text - Contains all text used in the ad, verbatim (text). For example,

> *CertainTeed leading in value since 1904 New triple 5" Cedar Impressions Perfection Shingles With a deep cedar grain taken directly from real shingles, T5" Perfection shingles joins the Cedar Impressions family with twelve designer colors and a matching mitered cornerpost. Cedar Impressions: ideal for the whole house or as classic accents. Learn more. Call 800-233-8990, code 1001, or visit www/certainteed.com/ct1001. Double 7" Perfection Shingles, Double 6-1/4" Half-round shingles 10" Random Hand-split shakes CertainTeed 100 since 1904 See us at the International Builder's Show, booth W1271. CertainTeed quality made certain. Satisfaction guaranteed. roofing siding insulation fence decking railing foundations pipe*

Text inches - is a measure of the number of square inches dedicated just to the text including between letter spacing. White space or graphic space is not included (numeric).

Graphic - Is there a picture used with the ad? yes=1 no =0, (dichotomous).

Graphic inches - The amount of square inches dedicated to a picture in the ad (numeric).

Graphic description - describes the picture(s) used within an advertisement (text). For example,

> *The left page primary graphic shows a clad exterior front elevation of a house. On the right page are four types of siding shown close up on the wall.*

Multiple products - Does the ad display multiple products? Yes =1 and no = 0 (dichotomous).

Percent of ad - percent of the ad that is dedicated to this product being described (numeric).

Percent of ad copy - percent of the ad copy that is dedicated to this product being described (numeric).

Percent of ad graphic - percent of the ad graphic that is dedicated to this product being described (numeric).

Insert - Is the ad an insert? Yes = 1 and no = 0 (dichotomous).

foldout - Does the ad fold out? Yes =1 and no =0 (dichotomous).

Paper weight - is the weight of the ad paper heavier than the average issue page? Yes =1 and no = 0 (dichotomous).

Special section - Is the ad included in a special section? Yes= 1 and no = 0 (dichotomous).

Product Attribute section

The next series of variables represent textual counts or number or references of product attribute categories for manufacturer siding brochures or product web pages.

Aesthetics - Count of aesthetically pleasing attributes mentioned within a piece of product promotion brochures or web pages. Terms such as *beauty* or *looks great* were coded into the aesthetic category (numeric).

Availability - This category refers to manufacturer statements of products being easily obtained in the market such as *convenient distribution* or *ease of sourcing* (numeric).

Code approval/certification - This category captured the number of third party references from manufacturers that bolstered the presentation of their products. Text referencing legitimate third parties such as *ASTM*, *Good Housekeeping*, *ISO 9000*, *association approved* or *building code approval* were tallied in this category (numeric).

Corrosion resistance - Count of text references to the corrosion resistant nature of a product such as *no chalking*, *rust resistant* or *corrosion resistant* (numeric).

Cost effectiveness - Count of text references to the economics of a product such as *adding value to a home*, *saving money* or any type of cost based rhetoric (numeric).

Customer service - Count of any references to *customer service* as a benefit (numeric).

Deadens sound - Count of references to sound insulating properties of siding materials such as *reduces outside noise* and other references to sound reducing properties (numeric).

Design flexibility - Count of references that infer design flexibility such as a *full array of colors*, *styles* and *textures*. In addition references to product or look variety were also captured as design flexibility (numeric).

Dimensional stability - Count of references that infer that the product doesn't change shape or size. Dimensional stability can be challenged by temperature change (mostly vinyl) or changes in moisture (wood products) (numeric).

Durability - Count of references to product durability such as *lasts a long time* or the product is *extremely durable* (numeric).

Ease of installation - This variable captures all references that imply that the product is easier to install, use or handle during the construction process (numeric).

Ease of maintenance - Captures all references for low product maintenance such as no cleaning needed or painting needed (numeric).

Energy efficiency - This category captures all references to energy efficiency or savings as a result of using a siding products including stabilizing temperature changes within a structure or insulating properties (numeric).

Performance under extreme circumstances - This category captures all references to a siding product holding up to extreme events of natures such as fire, hurricanes and earthquakes (numeric).

Environmental friendliness - This category captures any references to the “greenness” of a product or environmental benefits a product provides such as less waste or sustainable harvest (numeric).

Full product line offered - This category captures all references to manufacturers offering a full line of products that can be additional siding materials or other exterior accents such as trim, windows, etc.. (numeric).

Impact resistance - This category captures all references to a siding material’s impact resistance from outdoor items or weather events such as hail (numeric).

Insect and mold resistance - This category captures all references to pests that could potentially damage a siding product such as ants, termites, mold and decay fungi (numeric).

Moisture resistance -This category captures manufacturer promotion of a siding product’s moisture resistant features. Text references such as rain resistance, moisture barrier would be included in this category (numeric).

Non-toxic - This variable captures textual references of product non-toxicity. Text references such as inert, or no harmful by products would be included in this category (numeric).

Product integrity – This category refers to manufacturer statements that reflect the consistency or soundness of their products such as finest raw materials or product consistency (numeric).

Strength - This variable captures manufacturer references to products strength. Text examples included in this category include product rigidity, strength or toughness (numeric).

Quality attribute - This variable captures quality references by siding manufacturers across all facets of their operations from products quality to quality control in operations.

Sound company/product reputation - This variable captures manufacturer references that are intended to bolster their company or the product’s reputation. Examples are history in business and wide builder/consumer acceptance or recognition of the product or company.

Sun/ultra-violet/fade resistance - This variable measures the amount of manufacturer text entries that were categorized as reflective sun (fade) resistant properties. Textual references such as ultra-violet protected and holds up to the sun were entered into this category (numeric).

Technologically savvy - This category captures manufacturer references to technology either as a company or as used to manufacture, develop or support product delivery. Also references such as innovative or state-of-the-art are included in the category (numeric).

Temperature resistance - This variable represents manufacturer text entries that reflect product resistance to temperature changes or performance in extreme temperature conditions (numeric).

Warranty - The warranty category captures all text that specifically mentioned product warranties which included both substrate and finish warranty text (numeric).

Weather resistance - This variable includes all manufacturer text that references product weather resistance either using weather in the text or motioning resistance against Mother Nature or the elements (numeric).

Wind resistance - The wind resistance category captures all manufacturer text references to products withstanding wind loads. Text that refereed to wind test results or hurricane wind resistance were included in this category (numeric).

APPENDIX D – Ranked Attributes by Siding Material, Brochures / Web

Wood Composite (Brochures / Web)

n = 6 cases

	Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 6 of 160 cases	Mean Frequency Per Case (All WC)	Mean Frequency Per Page (FPP)	Median
1	Aesthetics	6	100%	50	8.33	.92	8
2	Easy to install	6	100%	42	7.00	.88	7
3	Design flexibility	6	100%	33	5.50	.65	4.5
4	Warranty	5	83.3%	46	7.67	.94	4.5
5	Cost effectiveness	5	83.3%	21	3.50	.46	4
6	Dimensional stability	5	83.3%	16	2.67	.36	2
7	Strength	4	66.7%	14	2.33	.29	1
8	Durability	4	66.7%	12	2.00	.23	2
9	Easy to maintain	4	66.7%	10	1.67	.22	1.5
10	Environmentally friendly	4	66.7%	7	1.17	.17	1
11	Moisture resistant	3	50.0%	13	2.17	.29	1.5
12	Quality	3	50.0%	11	1.83	.25	1.5
13	Weather resistant	3	50.0%	11	1.83	.23	1.5
14	Technologically savvy	3	50.0%	8	1.33	.22	.5
15	Product integrity	3	50.0%	6	1.00	.11	.5
16	Full product line offered	3	50.0%	5	.83	.08	.5
17	Insect/mold resistant	2	33.3%	12	2.00	.32	0
18	Code approval/certification	2	33.3%	10	1.67	.23	0
19	Company/product reputation	2	33.3%	5	.83	.09	0
20	Customer service	2	33.3%	4	.67	.11	0
21	Availability	2	33.3%	2	.33	.05	0
22	Temperature resistant	2	33.3%	2	.33	.05	0
23	Performs in extreme cond.	1	16.7%	2	.33	.06	0
24	Impact resistant	1	16.7%	1	.17	.02	0
	Corrosion resistance						
	Deadens sound						
	Energy efficient						
	Non-toxic						
	Sun/UV/fade resistant						
	Wind resistant						

Table 49 - Descending attribute frequencies, Wood Composites, Brochures / Web

5 Manufacturers, 6 brands

Manufacturer	Brand name	Manufacturer	Brand name
Collins Manufacturing	Collins True Wood	*Temple*	Temple
Georgia Pacific Hardboard	Georgia Pacific	*Pacific Wood Laminates*	Pacific Wood Laminates
Louisiana-Pacific	ABTCO-Hardboard		
	LP Smartside		

Solid Wood (Brochures / Web)

n = 26 cases

	Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 26 of 160 cases	Mean Frequency Per Case (All Wood)	Mean Frequency Per Page (FPP)	Median
1	Aesthetics	19	73.1%	113	4.35	1.50	3
2	Design flexibility	19	73.1%	73	2.81	1.15	1.5
3	Quality	18	69.2%	44	1.69	.77	1
4	Cost effectiveness	18	69.2%	41	1.58	.73	1
5	Dimensional stability	16	61.5%	40	1.54	.75	1
6	Easy to install	13	50.0%	61	2.35	.56	.5
7	Durability	13	50.0%	34	1.31	.60	.5
8	Company/prod. reputation	13	50.0%	16	.62	.32	.5
9	Moisture resistant	10	38.5%	22	.85	.32	0
10	Product integrity	10	38.5%	19	.73	.60	0
11	Environmentally friendly	10	38.5%	19	.73	.24	0
12	Code approval/certification	9	34.6%	21	.81	.36	0
13	Insect/mold resistant	9	34.6%	18	.69	.36	0
14	Customer service	9	34.6%	13	.50	.26	0
15	Warranty	7	26.9%	26	1.00	.43	0
16	Weather resistant	7	26.9%	13	.50	.15	0
17	Easy to maintain	7	26.9%	12	.46	.12	0
18	Strength	7	26.9%	12	.46	.11	0
19	Technologically savvy	7	26.9%	8	.31	.08	0
20	Full product line offered	7	26.9%	7	.27	.26	0
21	Energy efficient	6	23.1%	12	.46	.28	0
22	Performs in extreme cond.	4	15.4%	10	.38	.19	0
23	Availability	4	15.4%	6	.23	.09	0
24	Sun/UV/fade resistant	4	15.4%	5	.19	.03	0
25	Wind resistant	3	11.5%	4	.15	.05	0
26	Deadens sound	1	3.8%	2	.08	.06	0
27	Temperature resistant	1	3.8%	1	.04	.01	0
28	Corrosion resistance	1	3.8%	1	.04	.004	0
	Impact resistant						
	Non-toxic						

Table 50 - Descending attribute frequencies, Solid Wood, Brochures / Web

Solid Wood, 26 Manufacturers, 26 brands

Manufacturer	Brand name	Manufacturer	Brand Name
Canadian Forest Products	CANFOR	*Potlatch Corporation*	Potlatch
Cedar Valley, Inc.	Cedar Valley	*Premier Forest Products, Inc.*	Premier Cedar
Cedarsource	Cedarsource	*Roseburg Forest Products*	Roseburg
Columbia Cedar Inc.	Columbia Cedar	*Shakertown*	Shakertown
Elder Forest Products	Elder Forest Products	*Teal Cedar Products Ltd.*	Teal Cedar
Granville Manufacturing	Granville Manufacturing	*Twin Rivers Cedar Products*	Twin Rivers Cedar
Haida Forest Products	Haida	*Tyee Timber Products, Ltd.*	Tyee Cedar
Interfor	Interfor Cedar	*Ward Clapboard Mill*	Ward Clapboard Mill
Kluckwan, Inc.	K-Ply	*Welco USA/Skookum Lumber*	Skookum Cedar
Maibec	Maibec	*Westshore Specialties Ltd.*	Westshore Cedar
Northwest Forest Products	Northwest Cedar	*Weyerhaeuser*	Cedar One
Palco	Palco	*Woodtone Building Products*	Woodtone
Plum Creek	Plum Creek	*Wynndel Box & Lumber Co.*	Wyndell

Vinyl (Brochures / Web)

n = 73 cases

	Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 73 of 160 cases	Mean Freq Per Case (All Vinyl)	Mean Frequency Per Page (FPP)	Median
1	Aesthetics	71	97.4%	640	8.77	1.67	6
2	Design flexibility	70	95.90%	385	5.27	1.14	4
3	Warranty	70	95.9%	220	3.22	.59	2
4	Easy to maintain	60	82.2%	211	2.89	.54	2
5	Durability	56	76.7%	127	1.74	.37	1
6	Strength	55	75.3%	187	2.56	.47	2
7	Wind resistant	51	69.9%	132	1.81	.47	1
8	Quality	49	67.1%	161	2.21	.36	1
9	Technologically savvy	48	65.8%	153	2.10	.42	1
10	Weather resistant	48	65.8%	129	1.77	.34	1
11	Full product line offered	44	60.3%	96	1.32	.25	1
12	Cost effectiveness	42	57.54%	128	1.75	.26	1
13	Company/prod. reputation	39	53.4%	134	1.84	.33	1
14	Easy to install	39	53.4%	80	1.10	.29	1
15	Sun/UV/fade resistant	36	49.3%	96	1.32	.23	0
16	Product integrity	36	49.3%	79	1.08	.29	0
17	Impact resistant	33	45.2%	64	.88	.17	0
18	Code approval/certification	26	35.6%	164	2.25	.33	0
19	Temperature resistant	26	35.6%	47	.64	.14	0
20	Insect/mold resistant	20	27.4%	35	.48	.10	0
21	Dimensional stability	20	27.4%	33	.45	.07	0
22	Moisture resistant	17	23.3%	27	.37	.09	0
23	Performs in extreme cond.	17	23.3%	27	.37	.07	0
24	Customer service	10	13.7%	28	.38	.05	0
25	Availability	9	12.3%	14	.19	.02	0
26	Energy efficient	7	9.6%	41	.56	.10	0
27	Corrosion resistance	5	6.8%	5	.07	.03	0
28	Deadens sound	3	4.11%	5	.07	.01	0
29	Environmentally friendly	3	4.11%	4	.05	.01	0
30	Non-toxic	2	2.74%	2	.03	.01	0

Table 51 - Descending attribute frequencies, Vinyl, Brochures / Web

Vinyl 17 Manufacturers, 73 Brands

Manufacturer	Brand	Manufacturer	Brand
Alcoa	Alcoa Siding	*Mitten Vinyl Siding*	Mitten
	Cellwood	*Nailite*	Nailite
	Mastic	*Norandex*	Norandex
Amcraft	Amcraft	*Owens Corning*	Owens Corning
Associated Materials	Alside		Vytec
	Alside Architectural Classics	*Resource Materials Corp.*	RMC
	Alside Board & Batten	*Rollex Corporation*	Rollex Vinyl
	Alside Centerlock	*Royal Building Products*	Architectural
	Alside Charter Oak Energy Elite		Board & Batten
	Alside Charter Oak Ultimate		Cedar Series
	Alside Conquest		Colonial Beaded
	Alside Landscape		Designer Shake Hand Split
	Alside Odyssey Plus		Designer Shake Rough Sawn
	Alside Pelican Bay Hand Split Shakes		Duraplank
	Alside Pelican Bay Shakes		Journeymen
	Alside Seneca		Journeymen Laminates
	Alside Williamsport		Residential
	Gentek		Royal Building Products
Certainteed	Carolina Beaded		Woodland
	Cedar Impressions	*The Foundry*	The Foundry
	Certainteed	*Variform*	Ashton Heights
	Classic		Camden Pointe
	Hamilton		Durabuilt
	Main Street		Georgia-Pacific Vinyl
	Millenium		Napco American 76 Beaded
	Monogram		Napco American Comfort
	True Comfort		Napco American Heritage
	Vinyl Carpentry		Napco American Splendor
Crane	Crane		Napco American Splendor XL
Heartland	Heartland		Napco American Tradition
Kaycan	Kaycan		Nostalgia Series
Louisiana-Pacific	ABTCO		Nottingham
	Dakota		Timber oak
	Hudson Bay		Variform
	Maxim		Varigrain Preferred
	Norman Rockwell		
	Northern Star		

Aluminum (Brochures / Web)

n = 4 cases

	Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 4 of 160 cases	Mean Freq Per Case (All Alum)	Mean Frequency Per Page (FPP)	Median
1	Design flexibility	4	100%	19	4.75	1.75	5.0
2	Quality	4	100%	10	2.50	.76	2.5
3	Company/prod. reputation	4	100%	6	1.50	.56	1.5
4	Aesthetics	3	75%	17	4.25	1.59	4.5
5	Durability	3	75%	7	1.75	.44	1.5
6	Full product line offered	3	75%	6	1.50	.49	1.5
7	Easy to maintain	3	75%	6	1.50	.39	1.0
8	Warranty	2	50%	9	2.25	.82	2.0
9	Sun/UV/fade resistant	2	50%	4	1.00	.29	.5
10	Product integrity	2	50%	3	.75	.34	.5
11	Technologically savvy	2	50%	3	.75	.34	.5
12	Cost effectiveness	2	50%	3	.75	.24	.5
13	Temperature resistant	2	50%	2	.50	.19	.5
14	Code approval/certification	1	25%	2	.50	.10	0
15	Weather resistant	1	25%	2	.50	.10	0
16	Performs in extreme cond.	1	25%	1	.25	.14	0
17	Customer service	1	25%	1	.25	.05	0
18	Energy efficient	1	25%	1	.25	.05	0
19	Moisture resistant	1	25%	1	.25	.05	0
20	Strength	1	25%	1	.25	.05	0
	Availability						
	Corrosion resistance						
	Deadens sound						
	Dimensional stability						
	Easy to install						
	Environmentally friendly						
	Impact resistant						
	Insect/mold resistant						
	Non-toxic						
	Wind resistant						

Table 52 - Descending attribute frequencies, Aluminum, Brochures / Web

4 Manufacturers, 4 brands

Manufacturer	Brand name
Alcoa	Alcoa Siding
Kaycan	Kaycan Aluminum
Rollex Corporation	Rollex Aluminum
Variform	Napco Aluminum

Brick/Masonry (Brochures / Web)

n = 30 cases

	Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 30 of 160 cases	Mean Freq Per Case (All Brick)	Mean Frequency Per Page (FPP)	Median
1	Design flexibility	25	83.33%	104	3.47	.95	3
2	Aesthetics	24	80.0%	81	2.70	.70	2
3	Company/prod. reputation	24	80.00%	72	2.40	.81	2
4	Quality	23	76.7%	75	2.50	.85	2
5	Technologically savvy	17	56.67%	46	1.53	.48	1
6	Durability	15	50.0%	28	.93	.30	0.5
7	Cost effectiveness	14	46.7%	63	2.10	.46	0
8	Customer service	13	43.3%	42	1.40	.42	0
9	Code approval/certification	8	26.67%	28	.93	.19	0
10	Easy to maintain	8	26.67%	19	.63	.13	0
11	Availability	8	26.7%	9	.30	.08	0
12	Performs in extreme cond.	7	23.3%	14	.47	.11	0
13	Energy efficient	7	23.3%	14	.47	.10	0
14	Product integrity	7	23.3%	11	.37	.13	0
15	Strength	6	20.0%	8	.27	.08	0
16	Full product line offered	6	20.0%	8	.27	.07	0
17	Easy to install	5	16.7%	11	.37	.10	0
18	Moisture resistant	5	16.7%	10	.33	.06	0
19	Sun/UV/fade resistant	5	16.7%	6	.20	.05	0
20	Insect/mold resistant	5	16.7%	6	.20	.03	0
21	Environmentally friendly	4	13.3%	7	.23	.06	0
22	Deadens sound	4	13.3%	7	.23	.04	0
23	Weather resistant	4	13.3%	7	.23	.04	0
24	Corrosion resistance	3	10.0%	3	.10	.02	0
25	Impact resistant	3	10.0%	3	.10	.02	0
26	Warranty	2	6.7%	14	.47	.08	0
27	Temperature resistant	2	6.7%	3	.10	.02	0
28	Dimensional stability	2	6.7%	3	.10	.02	0
29	Wind resistant	2	6.7%	2	.07	.01	0
30	Non-toxic	1	3.33%	1	.03	.01	0

Table 53 - Descending attribute frequencies, Brick / Masonry, Brochures / Web

Brick / Masonry 30 Manufacturers, 30 Brands

Manufacturer	Brand	Manufacturer	Brand
Acme Brick	Acme	*Jenkins Brick Company*	Jenkins Brick
Belden	Belden	*Lawerenceville Brick*	Lawerenceville Brick
Boral	Boral	*Lee brick*	Lee Brick
Bowerston Shale	Bowerston	*Pacific Clay Products*	Pacific Clay
Brampton Brick	Brampton Brick	*Pine Hall Brick Company*	Pine Hall Brick
Carolina Ceramics	Carolina Brick	*Redland Brock Inc.*	Redland Brick
Columbus Brick	Columbus Brick	*Robinson Brick Company*	Robinson Brick
Eldorado Stone	Eldorado	*St. Joe Brick Works, Inc.*	St. Joe Brick
EZ Rock	EZRock	*Styles & Hart Brick Company*	Styles & Hart Brick
General Shale Brick, Inc.	General Shale	*Summit Brick & Tile Company*	Summit Brick
Glen-Gery Corporation	Glen-Gery	*Taylor Clay Products Company*	Taylor Brick
Hanson Brick	Hanson Brick	*The McAvoy Brick Company*	McAvoy Brick
Hebron Brick	Hebron Brick	*The Shaw Group Ltd.*	Shaw Brick
Henry Brick Company	Henry Brick	*Triangle Brick Company*	Triangle Brick
IXL Brick	IXL Brick	*Watsontown Brick Company*	Watsontown Brick

Stucco (Brochures / Web)

n = 7 cases

	Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 7 of 160 cases	Mean Freq Per Case (All Stucco)	Mean Frequency Per Page (FPP)	Median
1	Design flexibility	6	85.7%	35	5.0	.92	3
2	Aesthetics	6	85.7%	15	2.14	.30	2
3	Company/product reputation	6	85.7%	10	1.43	.33	2
4	Quality	5	71.4%	27	3.86	.77	3
5	Product integrity	5	71.4%	6	.86	.16	1
6	Code approval/certification	4	57.1%	17	2.43	.53	2
7	Cost effectiveness	4	57.1%	15	2.14	.30	1
8	Customer service	4	57.1%	14	2.00	.29	2
9	Easy to maintain	4	57.1%	11	1.57	.27	2
10	Durability	4	57.1%	7	1.00	.27	1
11	Technologically savvy	4	57.1%	6	.86	.23	1
12	Warranty	3	42.9%	14	2.00	.27	0
13	Easy to install	3	42.9%	13	1.86	.36	0
14	Energy efficient	3	42.9%	8	1.14	.15	0
15	Weather resistant	3	42.9%	7	1.00	.14	0
16	Insect/mold resistant	3	42.9%	6	.86	.14	0
17	Moisture resistant	2	28.6%	6	.86	.10	0
18	Availability	2	28.6%	2	.29	.05	0
19	Performs in extreme cond.	1	14.3%	4	.57	.14	0
20	Full product line offered	1	14.3%	4	.57	.14	0
21	Corrosion resistance	1	14.3%	1	.14	.04	0
22	Impact resistant	1	14.3%	1	.14	.04	0
23	Strength	1	14.3%	1	.14	.04	0
24	Environmentally friendly	1	14.3%	1	.14	.02	0
	Deadens sound						
	Dimensional stability						
	Non-toxic						
	Sun/UV/fade resistant						
	Temperature resistant						
	Wind resistant						

Table 54 - Descending attribute frequencies, Stucco, Brochures / Web

7 Manufacturers, 7 Brands

Manufacturer	Brand	Manufacturer	Brand
California Stucco	California Stucco	*Monolite Stucco*	Monolite
Dryvit	Dryvit	*Quickrete*	Quickrete
LaHabra Stucco	LaHabra	*Texas EIFs*	Texas EIFs
Merlex Stucco	Merlex		

Fiber Cement (Brochures / Web)

n = 5 cases

	Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 5 of 160 cases	Mean Freq Per Case (All FC)	Mean Frequency Per Page (FPP)	Median
1	Design flexibility	5	100%	27	5.40	.67	3
2	Aesthetics	5	100%	24	4.80	.73	5
3	Warranty	4	80%	16	3.20	.56	4
4	Durability	4	80%	11	2.20	.45	2
5	Insect/mold resistant	4	80%	9	1.80	.39	2
6	Dimensional stability	4	80%	7	1.40	.40	1
7	Moisture resistant	4	80%	7	1.40	.20	1
8	Easy to maintain	4	80%	5	1.00	.29	1
9	Code approval/certification	3	60%	11	2.20	.33	1
10	Performs in extreme cond.	3	60%	9	1.80	.55	2
11	Easy to install	3	60%	9	1.80	.26	1
12	Technologically savvy	3	60%	6	1.20	.20	1
13	Weather resistant	3	60%	3	.60	.06	1
14	Customer service	2	40%	11	2.20	.34	0
15	Strength	2	40%	5	1.00	.13	0
16	Full product line offered	2	40%	4	.80	.13	0
17	Product integrity	2	40%	4	.80	.10	0
18	Impact resistant	2	40%	3	.60	.08	0
19	Temperature resistant	2	40%	3	.60	.08	0
20	Wind resistant	2	40%	3	.60	.06	0
21	Company/product reputation	1	20%	8	1.60	.29	0
22	Quality	1	20%	6	1.20	.22	0
23	Environmentally friendly	1	20%	2	.40	.05	0
24	Sun/UV/fade resistant	1	20%	1	.20	.04	0
25	Cost effectiveness	1	20%	1	.20	.03	0
	Availability						
	Corrosion resistance						
	Deadens sound						
	Energy efficient						
	Non-toxic						

Table 55 - Descending attribute frequencies, Fiber Cement, Brochures / Web

3 Manufacturers, 4 brands

Manufacturer	Brand
Certainteed	Weatherboards (2 different brochures)
James Hardie	Cemplank
	James Hardie
Nichiha	Nichiha

Steel (Brochures / Web)

n = 9 cases

	Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 9 of 160 cases	Mean Freq Per Case (All Steel)	Mean Frequency Per Page (FPP)	Median
1	Aesthetics	9	100%	44	4.89	1.61	3
2	Design flexibility	8	88.9%	41	4.56	1.62	3
3	Quality	7	77.8%	16	1.78	.67	2
4	Strength	6	66.7%	21	2.33	1.04	1
5	Code approval/certification	6	66.7%	12	1.33	.46	1
6	Easy to install	5	55.6%	17	1.89	.55	1
7	Cost effectiveness	5	55.6%	14	1.56	.51	1
8	Weather resistant	5	55.6%	12	1.33	.48	1
9	Warranty	5	55.6%	11	1.22	.46	1
10	Corrosion resistance	4	44.4%	14	1.56	.39	0
11	Durability	4	44.4%	9	1.00	.38	0
12	Moisture resistant	3	33.3%	8	.89	.44	0
13	Environmentally friendly	2	22.2%	19	2.11	.33	0
14	Customer service	2	22.2%	6	.67	.13	0
15	Company/product reputation	2	22.2%	5	.56	.20	0
16	Easy to maintain	2	22.2%	5	.56	.16	0
17	Technologically savvy	2	22.2%	5	.56	.22	0
18	Wind resistant	2	22.2%	4	.44	.19	0
19	Impact resistant	2	22.2%	3	.33	.13	0
20	Availability	2	22.2%	2	.22	.05	0
21	Full product line offered	2	22.2%	2	.22	.07	0
22	Product integrity	2	22.2%	2	.22	.09	0
23	Performs in extreme cond.	1	11.1%	6	.67	.22	0
24	Insect/mold resistant	1	11.1%	5	.56	.19	0
25	Energy efficient	1	11.1%	2	.22	.03	0
26	Sun/UV/fade resistant	1	11.1%	1	.11	.06	0
	Deadens sound						
	Dimensional stability						
	Non-toxic						
	Temperature resistant						

Table 56 - Descending attribute frequencies, Steel, Brochures / Web

8 Manufacturers, 9 brands

Manufacturer	Brand		
Associated Materials	Alside Steel	Nucor	Nucor Building Sys.
Border Steel	Border Steel	Rollex Corp	Rollex
Fabral	Fabral	US Steel	USS
International Steel	ISTG	Wheeling Corrugating Co/	Century Drain; Channel Drain

APPENDIX E – Ranked Attributes by Siding Material, Magazine Ads

Wood Composite (Magazine Ads)

n = 2 cases

	Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 2 of 90 cases	Mean Frequency Per Case	Median
1	Aesthetics	2	100%	8	4	4
2	Easy to install	2	100%	6	3	3
3	Durability	2	100%	4	2	2
4	Cost effectiveness	2	100%	2	1	1
5	Design Flexibility	2	100%	2	1	1
6	Warranty offered	2	100%	2	1	1
	Availability					
	Code approval/certification					
	Company/prod. reputation					
	Customer service					
	Deadens sounds					
	Easy to maintain					
	Energy efficient					
	Full product line offered					
	Impact resistant					
	Insect resistant					
	Moisture resistant					
	Performs in extreme cond.					
	Product integrity					
	Quality					
	Strength					
	Sun resistant					
	Technologically savvy					
	Weather resistant					
	Wind resistant					

Table 57 - Descending attribute frequencies, Wood Composites, Magazine Ads

Wood Composite Advertisement Descriptives (2 ads)

	Ad size	Layout, % of page	2005 Ad Rate
Minimum	78.8 in.^{2}	100 %	$14,330
Maximum	92.1 in.^{2}	100 %	$17,180
Range	13.4 in.^{2}	0	$2,850
Mean	85.4 in.^{2}	100 %	$15,755
Median	85.4 in.^{2}	100 %	$15,755

Ads per Magazine

Builder - 1

Professional Builder - 1

Solid Wood (Magazine Ads)

n = 22 cases

	Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 22 of 90 cases	Mean Frequency Per Case	Median
1	Design Flexibility	15	68.2%	18	.82	1
2	Aesthetics	13	59.1%	14	.64	1
3	Company/prod. reputation	10	45.5%	11	.5	0
4	Cost effectiveness	8	36.4%	11	.5	0
5	Warranty offered	7	31.8%	8	.36	0
6	Quality	6	27.3%	8	.36	0
7	Customer service	5	22.7%	5	.23	0
8	Easy to maintain	5	22.7%	5	.23	0
9	Full product line offered	5	22.7%	5	.23	0
10	Easy to install	4	18.2%	9	.41	0
11	Durability	4	18.2%	5	.23	0
12	Technologically savvy	4	18.2%	4	.18	0
13	Availability	2	9.1%	2	.09	0
14	Moisture resistant	1	4.5%	1	.05	0
15	Product integrity	1	4.5%	1	.05	0
16	Sun resistant	1	4.5%	1	.05	0
17	Weather resistant	1	4.5%	1	.05	0
	Code approval/certification					
	Deadens sounds					
	Energy efficient					
	Impact resistant					
	Insect resistant					
	Performs in extreme cond					
	Strength					
	Wind Resistant					

Table 58 - Descending attribute frequencies, Solid Wood, Magazine Ads

Solid Wood Advertisement Descriptives (22 ads)

	Ad size	Layout, % of page	2005 Ad Rate
Minimum	7.8 in.^{2}	0.08 %	$1,135
Maximum	93.6 in.^{2}	100.0 %	$21,220
Range	85.8 in.^{2}	99.9 %	$20,085
Mean	34.3 in.^{2}	37.8 %	$6,347
Median	23.4 in.^{2}	25.0 %	$5,043

Ads per Magazine

Fine Homebuilding - 18

Journal of Light Construction - 4

Vinyl (Magazine Ads)

n = 44 cases

	Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 44 of 90 cases	Mean Frequency Per Case	Median
1	Quality	35	79.5%	42	.95	1
2	Company/product reputation	34	77.3%	108	2.45	3
3	Design Flexibility	31	70.5 %	105	2.39	1.5
4	Full product line offered	28	63.6%	42	.95	1
5	Aesthetics	24	54.5%	56	1.27	1
6	Warranty offered	23	52.3%	37	.84	1
7	Cost effectiveness	19	43.2%	20	.45	0
8	Technologically savvy	15	34.1%	29	.65	0
9	Easy to maintain	14	31.8%	14	.32	0
10	Product integrity	12	27.3%	18	.41	0
11	Sun resistant	10	22.7%	22	.50	0
12	Customer service	9	20.5%	11	.25	0
13	Strength	8	18.2%	17	.39	0
14	Easy to install	7	15.9%	10	.23	0
15	Energy efficient	7	15.9%	10	.23	0
16	Impact resistant	6	13.6%	10	.23	0
17	Code approval/certification	6	13.6%	6	.14	0
18	Moisture resistant	5	11.4%	5	.11	0
19	Wind resistant	3	6.8%	6	.14	0
20	Deadens sounds	3	6.8%	3	.07	0
21	Durability	3	6.8%	3	.07	0
22	Weather resistant	3	6.8%	3	.07	0
23	Insect resistant	1	2.3%	1	.02	0
	Corrosion resistance					
	Performs in extreme conditions					

Table 59 - Descending attribute frequencies, Vinyl, Magazine Ads

Vinyl Advertisement Descriptives (44 ads)

	Ad size	Layout, % of page	2005 Ad Rate
Minimum	18.1 $in.^2$	22.2 %	$1,760
Maximum	630.0 $in.^2$	100.0 %	$137,440
Range	611.9 $in.^2$	77.8 %	$135,680
Mean	107.6 $in.^2$	92.7 %	$19,670
Median	82.7 $in.^2$	100.0 %	$15,250

<u>Ads per Magazine</u>

Builder **-** 10
Journal of Light Construction **-** 10
Remodeling **-** 12
Professional Builder **-** 7
Professional Remodeler **-** 5

Brick/Masonry (Magazine Ads)

n = 10 cases

	Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 10 of 90 cases	Mean Frequency Per Case	Median
1	Design Flexibility	10	100%	42	4.20	4
2	Aesthetics	10	100%	27	2.70	2
3	Cost effectiveness	10	100%	2	.20	0
4	Easy to install	7	70%	7	.70	1
5	Easy to maintain	7	70%	7	.70	1
6	Warranty offered	6	60%	6	.60	0
7	Full product line offered	2	20%	4	.40	0
8	Availability	2	20%	3	.30	0
9	Company/product reputation	2	20%	2	.20	0
10	Product integrity	1	10%	2	.20	0
11	Quality	1	10%	2	.20	0
12	Customer service	1	10%	1	.10	0
13	Durability	1	10%	1	.10	0
14	Weather resistant	1	10%	1	.10	0
	Code approval / certification					
	Corrosion resistance					
	Deadens sounds					
	Energy efficient					
	Performs in extreme conditions					
	Environmentally friendly					
	Impact resistant					
	Insect resistant					
	Moisture resistant					
	Non-toxic					
	Strength					

Table 60 - Descending attribute frequencies, Brick / Masonry, Magazine Ads

Brick / Masonry Advertisement Descriptives (10 Ads)

	Ad size	Layout, % of page	2005 Ad Rate
Minimum	78.8 in.^{2}	100%	$14,330
Maximum	276.4 in.^{2}	100 %	$56,045
Range	197.6 in.^{2}	0 %	$41,715
Mean	105.2 in.^{2}	100 %	$19,927
Median	82.7 in.^{2}	100 %	$17,180

Ads per Magazine

Builder - 6

Professional Builder - 4

Fiber Cement (Magazine Ads)

n = 12 cases

	Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 12 of 90 cases	Mean Frequency Per Case	Median
1	Company/product reputation	12	100%	36	3.00	3
2	Quality	12	100%	12	1.00	1
3	Cost effectiveness	11	91.6%	11	.92	1
4	Full product line offered	11	91.6%	11	.92	1
5	Design Flexibility	9	75.0%	51	4.25	6
6	Aesthetics	4	33.3%	10	.83	0
7	Performs in extreme conditions	4	33.3%	6	.50	0
8	Easy to maintain	4	33.3%	4	.33	0
9	Warranty offered	4	33.3%	4	.33	0
10	Moisture resistant	3	25%	3	.25	0
11	Product integrity	3	25%	3	.25	0
12	Strength	2	16.7%	2	.17	0
	Availability					
	Code approval/certification					
	Corrosion resistance					
	Customer service					
	Deadens sounds					
	Durability					
	Easy to install					
	Energy efficient					
	Environmentally friendly					
	Impact resistant					
	Insect resistant					
	Non-toxic					
	Sun resistant					

Table 61 - Descending attribute frequencies, Fiber Cement, Magazine Ads

Fiber Cement Advertisement Descriptives (12 Ads)

	Ad size	Layout, % of page	2005 Ad Rate
Minimum	78.8 in.^{2}	100 %	$9,430
Maximum	184.3 in.^{2}	100 %	$34,360
Range	105.5 in.^{2}	0	$24,930
Mean	99.8 in.^{2}	100 %	$16,847
Median	82.7 in.^{2}	100 %	$15,250

Ads per Magazine

***Builder* -** 3
***Journal of Light Construction* -** 2
***Remodeling* -** 3
***Professional Builder* -** 2
***Professional Remodeler* -** 2

APPENDIX F – Ranked Attributes by Siding Material, Combined Databases

Wood Composite (Combined Databases)

n = 8 cases
6 Ads, 2 Brochure / Web

	Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 8 of 250 cases	Mean Frequency Per Case	Mean Frequency Per Page (FPP)*
1	Aesthetics	8	100%	58	7.25	1.69
2	Easy to install	8	100%	48	6.00	1.41
3	Design Flexibility	8	100%	35	4.38	.74
4	Warranty offered	7	87.5%	48	6.00	.95
5	Cost effectiveness	7	87.5%	23	2.88	.59
6	Durability	6	75.0%	16	2.00	.67
7	Dimensional stability	5	62.5%	16	2.00	.27
8	Strength	4	50.0%	14	1.75	.22
9	Easy to maintain	4	50.0%	10	1.25	.17
10	Environmentally friendly	4	50.0%	7	.88	.13
11	Moisture resistant	3	37.5%	13	1.63	.22
12	Quality	3	37.5%	11	1.37	.19
13	Weather resistant	3	37.5%	11	1.38	.17
14	Technologically savvy	3	37.5%	8	1.00	.17
15	Product integrity	3	37.5%	6	.75	.08
16	Full product line offered	3	37.5%	5	.63	.06
17	Insect resistant	2	25.0%	12	1.50	.24
18	Code approval/certification	2	25.0%	10	1.25	.17
19	Company/prod. reputation	2	25.0%	5	.63	.06
20	Customer service	2	25.0%	4	.50	.08
21	Availability	2	25.0%	2	.25	.04
22	Temperature resistant	2	25.0%	2	.25	.04
23	Performs in extreme cond.	1	12.5%	2	.25	.04
24	Impact resistant	1	12.5%	1	.13	.02
	Corrosion resistance					
	Deadens sounds					
	Energy efficient					
	Non-toxic					
	Sun resistant					
	Wind resistant					

Table 62 - Descending attribute frequencies, Wood Composites, Combined Databases

*FPP = (Attribute count total) / (NbrPages * %dedicatedToSiding)
Mean FPP = (∑FPP) / n
for n=250 cases

Solid Wood (Combined Databases)

n = 48 cases
22 Ads, 26 Brochure / Web

	Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 48 of 250 cases	Mean Frequency Per Case	Mean Frequency Per Page (FPP)*
1	Design Flexibility	34	70.8%	91	1.90	1.00
2	Aesthetics	32	66.7%	127	2.65	1.10
3	Cost effectiveness	26	54.2%	52	1.08	.62
4	Quality	24	50.0%	52	1.08	.58
5	Company/prod. reputation	23	47.9%	27	.56	.40
6	Easy to install	17	35.4%	70	1.46	.49
7	Durability	17	35.4%	39	.81	.43
8	Dimensional stability	16	33.3%	40	.83	.41
9	Warranty offered	14	29.2%	34	.71	.40
10	Customer service	14	29.2%	18	.38	.24
11	Easy to maintain	12	25.0%	17	.35	.17
12	Full product line offered	12	25.0%	12	.25	.25
13	Moisture resistant	11	22.9%	23	.48	.20
14	Product integrity	11	22.9%	20	.42	.34
15	Technologically savvy	11	22.9%	12	.25	.13
16	Environmentally friendly	10	20.1%	19	.40	.13
17	Code approval/certification	9	18.8%	21	.44	.20
18	Insect resistant	9	18.8%	18	.38	.19
19	Weather resistant	8	16.7%	14	.29	.10
20	Strength	7	14.6%	12	.25	.06
21	Energy efficient	6	12.5%	12	.25	.15
22	Availability	6	12.5%	8	.17	.09
23	Sun resistant	5	10.4%	6	.13	.04
24	Performs in extreme cond.	4	8.3%	10	.21	.10
25	Wind resistant	3	6.3%	4	.08	.03
26	Deadens sounds	1	2.1%	2	.04	.03
27	Corrosion resistance	1	2.1%	1	.02	.00
28	Temperature resistant	1	2.1%	1	.02	.01
	Impact resistant					
	Non-toxic					

Table 63 - Descending attribute frequencies, Solid Wood, Combined Databases

*FPP = (Attribute count total) / (NbrPages * %dedicatedToSiding)
Mean FPP = $(\sum \text{FPP}) / n$
for n=250 cases

Vinyl (Combined Databases)

n = 117 cases
44 Ads, 73 Brochure / Web

	Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 117 of 250 cases	Mean Frequency Per Case	Mean Frequency Per Page (FPP)*
1	Design Flexibility	101	86.3%	490	4.19	1.61
2	Aesthetics	95	81.2%	696	5.95	1.52
3	Warranty offered	93	79.5%	272	2.32	.69
4	Quality	83	70.9%	203	1.74	.58
5	Company/prod. reputation	74	63.2%	242	2.07	1.13
6	Easy to maintain	74	63.2%	225	1.92	.45
7	Full product line offered	72	61.5%	138	1.18	.51
8	Strength	63	53.8%	204	1.74	.44
9	Technologically savvy	63	53.8%	182	1.56	.51
10	Cost effectiveness	61	52.1%	148	1.26	.34
11	Durability	59	50.4%	130	1.11	.25
12	Wind resistant	54	46.2%	138	1.18	.34
13	Weather resistant	51	43.6%	132	1.13	.24
14	Product integrity	48	41.0%	97	.83	.33
15	Sun resistant	46	39.3%	118	1.01	.33
16	Easy to install	46	39.3%	90	.77	.26
17	Impact resistant	39	33.3%	74	.63	.19
18	Code approval/certification	32	27.4%	170	1.45	.26
19	Temperature resistant	26	22.2%	47	.40	.09
20	Moisture resistant	22	18.8%	32	.27	.10
21	Insect resistant	21	17.9%	36	.31	.07
22	Dimensional stability	20	17.1%	33	.28	.04
23	Customer service	19	16.2%	39	.33	.12
24	Performs in extreme cond.	17	14.5%	27	.23	.05
25	Energy efficient	14	12.0%	51	.44	.15
26	Availability	9	7.7%	14	.12	.01
27	Deadens sounds	6	5.1%	8	.07	.03
28	Corrosion resistance	5	4.3%	5	.04	.02
29	Environmentally friendly	3	2.6%	4	.03	.01
30	Non-toxic	2	1.7%	2	.02	.00

Table 64 - Descending attribute frequencies, Vinyl, Combined Databases

*FPP = (Attribute count total) / (NbrPages * %dedicatedToSiding)
Mean FPP = $(\sum FPP) / n$
for n=250 cases

Aluminum (Combined Databases)

n = 4 cases
0 Ads, 4 Brochure / Web

	Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 4 of 250 cases	Mean Frequency Per Case	Mean Frequency Per Page (FPP)*
1	Design flexibility	4	100%	19	4.75	1.75
2	Quality	4	100%	10	2.50	.76
3	Company/prod. reputation	4	100%	6	1.50	.56
4	Aesthetics	3	75%	17	4.25	1.59
5	Durability	3	75%	7	1.75	.44
6	Full product line offered	3	75%	6	1.50	.49
7	Easy to maintain	3	75%	6	1.50	.39
8	Warranty	2	50%	9	2.25	.82
9	Sun/UV/fade resistant	2	50%	4	1.00	.29
10	Product integrity	2	50%	3	.75	.34
11	Technologically savvy	2	50%	3	.75	.34
12	Cost effectiveness	2	50%	3	.75	.24
13	Temperature resistant	2	50%	2	.50	.19
14	Code approval/certification	1	25%	2	.50	.10
15	Weather resistant	1	25%	2	.50	.10
16	Performs in extreme cond.	1	25%	1	.25	.14
17	Customer service	1	25%	1	.25	.05
18	Energy efficient	1	25%	1	.25	.05
19	Moisture resistant	1	25%	1	.25	.05
20	Strength	1	25%	1	.25	.05
	Availability					
	Corrosion resistance					
	Deadens sound					
	Dimensional stability					
	Easy to install					
	Environmentally friendly					
	Impact resistant					
	Insect/mold resistant					
	Non-toxic					
	Wind resistant					

Table 65 - Descending attribute frequencies, Aluminum, Combined Databases

***No Magazine Advertisements for Aluminum**

*FPP = (Attribute count total) / (NbrPages * %dedicatedToSiding)
Mean FPP = $(\sum FPP) / n$ for n=250 cases

Brick / Masonry (Combined Databases)

n = 40 cases
10 Ads, 30 Brochure / Web

	Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 40 of 250 cases	Mean Frequency Per Case	Mean Frequency Per Page (FPP)*
1	Design Flexibility	35	87.5%	146	3.65	1.76
2	Aesthetics	34	85.0%	108	2.70	1.20
3	Company/prod. reputation	26	65.0%	74	1.85	.66
4	Quality	24	60.0%	77	1.92	.69
5	Cost effectiveness	24	60.0%	65	1.63	.39
6	Technologically savvy	17	42.5%	46	1.15	.36
7	Durability	16	40.0%	29	.73	.25
8	Easy to maintain	15	37.5%	26	.65	.28
9	Customer service	13	32.5%	43	1.08	.34
10	Easy to install	12	30.0%	18	.45	.25
11	Availability	10	25.0%	12	.30	.14
12	Code approval/certification	8	20.0%	28	.70	.14
13	Warranty offered	8	20.0%	20	.50	.21
14	Product integrity	8	20.0%	13	.32	.15
15	Full product line offered	8	20.0%	12	.30	.15
16	Energy efficient	7	17.5%	14	.35	.08
17	Performs in extreme cond.	7	17.5%	14	.35	.08
18	Strength	6	15.0%	8	.20	.06
19	Moisture resistant	5	12.5%	10	.25	.04
20	Weather resistant	5	12.5%	8	.20	.05
21	Insect resistant	5	12.5%	6	.15	.03
22	Sun resistant	5	12.5%	6	.15	.03
23	Deadens sounds	4	10.0%	7	.18	.03
24	Environmentally friendly	4	10.0%	7	.18	.05
25	Corrosion resistance	3	7.5%	3	.08	.01
26	Impact resistant	3	7.5%	3	.08	.01
27	Dimensional stability	2	5.0%	3	.08	.01
28	Temperature resistant	2	5.0%	3	.08	.02
29	Wind resistant	2	5.0%	2	.05	.01
30	Non-toxic	1	2.5%	1	.03	.01

Table 66 - Descending attribute frequencies, Brick / Masonry, Combined Databases

*FPP = (Attribute count total) / (NbrPages * %dedicatedToSiding)
Mean FPP = $(\sum FPP) / n$ for n=250 cases

Stucco (Combined Databases)

n = 7 cases
0 Ads, 7 Brochure / Web

	Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 7 of 250 cases	Mean Frequency Per Case	Mean Frequency Per Page (FPP)*
1	Design flexibility	6	85.7%	35	5.0	.92
2	Aesthetics	6	85.7%	15	2.14	.30
3	Company/product reputation	6	85.7%	10	1.43	.33
4	Quality	5	71.4%	27	3.86	.77
5	Product integrity	5	71.4%	6	.86	.16
6	Code approval/certification	4	57.1%	17	2.43	.53
7	Cost effectiveness	4	57.1%	15	2.14	.30
8	Customer service	4	57.1%	14	2.00	.29
9	Easy to maintain	4	57.1%	11	1.57	.27
10	Durability	4	57.1%	7	1.00	.27
11	Technologically savvy	4	57.1%	6	.86	.23
12	Warranty	3	42.9%	14	2.00	.27
13	Easy to install	3	42.9%	13	1.86	.36
14	Energy efficient	3	42.9%	8	1.14	.15
15	Weather resistant	3	42.9%	7	1.00	.14
16	Insect/mold resistant	3	42.9%	6	.86	.14
17	Moisture resistant	2	28.6%	6	.86	.10
18	Availability	2	28.6%	2	.29	.05
19	Performs in extreme cond.	1	14.3%	4	.57	.14
20	Full product line offered	1	14.3%	4	.57	.14
21	Corrosion resistance	1	14.3%	1	.14	.04
22	Impact resistant	1	14.3%	1	.14	.04
23	Strength	1	14.3%	1	.14	.04
24	Environmentally friendly	1	14.3%	1	.14	.02
	Deadens sound					
	Dimensional stability					
	Non-toxic					
	Sun/UV/fade resistant					
	Temperature resistant					
	Wind resistant					

Table 67 - Descending attribute frequencies, Stucco, Combined Databases

***No Magazine Advertisements for Stucco**

*FPP = (Attribute count total) / (NbrPages * %dedicatedToSiding)
Mean FPP = (∑FPP) / n for n=250 cases

Fiber Cement (Combined Databases)

n = 17 cases
12 Ads, 5 Brochure / Web

	Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 17 of 250 cases	Mean Frequency Per Case	Mean Frequency Per Page (FPP)*
1	Design Flexibility	14	82.4%	78	4.59	3.20
2	Company/prod. reputation	13	76.5%	44	2.59	2.20
3	Quality	13	76.5%	18	1.06	.77
4	Full product line offered	13	76.5%	15	.88	.69
5	Cost effectiveness	12	70.6%	12	.71	.65
6	Aesthetics	9	52.9%	34	2.00	.80
7	Warranty offered	8	47.1%	20	1.18	.40
8	Easy to maintain	8	47.1%	9	.53	.32
9	Performs in extreme cond.	7	41.2%	15	.88	.51
10	Moisture resistant	7	41.2%	10	.59	.24
11	Product integrity	5	29.4%	7	.41	.21
12	Durability	4	23.5%	11	.65	.13
13	Insect resistant	4	23.5%	9	.53	.11
14	Dimensional stability	4	23.5%	7	.41	.12
15	Strength	4	23.5%	7	.41	.15
16	Code approval/certification	3	17.6%	11	.65	.10
17	Easy to install	3	17.6%	9	.53	.08
18	Technologically savvy	3	17.6%	6	.35	.06
19	Weather resistant	3	17.6%	3	.18	.02
20	Customer service	2	11.8%	11	.65	.10
21	Impact resistant	2	11.8%	3	.18	.02
22	Temperature resistant	2	11.8%	3	.18	.02
23	Wind resistant	2	11.8%	3	.18	.02
24	Environmentally friendly	1	5.9%	2	.12	.01
25	Sun resistant	1	5.9%	1	.06	.01
	Availability					
	Corrosion resistance					
	Deadens sounds					
	Energy efficient					
	Non-toxic					

Table 68 - Descending attribute frequencies, Fiber Cement, Combined Databases

*FPP = (Attribute count total) / (NbrPages * %dedicatedToSiding)
Mean FPP = (∑FPP) / n for n=250 cases

Steel (Combined Databases)

n = 9 cases
0 Ads, 9 Brochure / Web

	Attribute	# cases mentioning attribute at lease once	% of cases mentioning attribute at least once	Total mentions, 9 of 250 cases	Mean Frequency Per Case	Mean Frequency Per Page (FPP)*
1	Aesthetics	9	100%	44	4.89	1.61
2	Design flexibility	8	88.9%	41	4.56	1.62
3	Quality	7	77.8%	16	1.78	.67
4	Strength	6	66.7%	21	2.33	1.04
5	Code approval/certification	6	66.7%	12	1.33	.46
6	Easy to install	5	55.6%	17	1.89	.55
7	Cost effectiveness	5	55.6%	14	1.56	.51
8	Weather resistant	5	55.6%	12	1.33	.48
9	Warranty	5	55.6%	11	1.22	.46
10	Corrosion resistance	4	44.4%	14	1.56	.39
11	Durability	4	44.4%	9	1.00	.38
12	Moisture resistant	3	33.3%	8	.89	.44
13	Environmentally friendly	2	22.2%	19	2.11	.33
14	Customer service	2	22.2%	6	.67	.13
15	Company/product reputation	2	22.2%	5	.56	.20
16	Easy to maintain	2	22.2%	5	.56	.16
17	Technologically savvy	2	22.2%	5	.56	.22
18	Wind resistant	2	22.2%	4	.44	.19
19	Impact resistant	2	22.2%	3	.33	.13
20	Availability	2	22.2%	2	.22	.05
21	Full product line offered	2	22.2%	2	.22	.07
22	Product integrity	2	22.2%	2	.22	.09
23	Performs in extreme cond.	1	11.1%	6	.67	.22
24	Insect/mold resistant	1	11.1%	5	.56	.19
25	Energy efficient	1	11.1%	2	.22	.03
26	Sun/UV/fade resistant	1	11.1%	1	.11	.06
	Deadens sound					
	Dimensional stability					
	Non-toxic					
	Temperature resistant					

Table 69 - Descending attribute frequencies, Steel, Combined Databases

***No Magazine Advertisements for Steel**

*FPP = (Attribute count total) / (NbrPages * %dedicatedToSiding)
Mean FPP = (∑FPP) / n for n=250 cases

APPENDIX G – Attribute Analysis

The following attributes are ranked by promotional frequency as found in the combined Magazine Ad and Brochure / Web databases.

Design flexibility

Design flexibility describes the ability of a siding material to be incorporated within numerous architectural styles, housing designs and siding layout schemes. Design flexibility was the most promoted attribute for all categories of siding materials. Manufacturer promotional texts such as "*color variety,*" "*Your home takes shape with our complete array of profiles,*" and "*style variety*" were included in the design flexibility category. By far, fiber cement siding manufacturers promote design flexibility most frequently. Fiber cement manufacturers promote variety of colors, finishes, styles, edges and textures. Wood composite siding manufacturers promoted design flexibility the least of all siding classifications, but still promote it as one of their top features (Reference *Attribute Promotion by Siding Material* section in this report.) Brick manufacturers promoted color and texture variety heavily. For example, "*Smooth bricks. Rough bricks. Bricks with a flat even color. Bricks that mix myriads of shades and hues. Rich reds. Hearty earth tones. Soft pastels. Evocative blends...*" Aluminum siding manufacturers promoted a wide variety of color offerings. Stucco producers highlighted their product's color and texture, and heavily promoted the ability to produce custom colors and textures.

Siding material	N	Mean Freq per Page	Median
fiber cement	17	3.20	3.00
brick/masonry	40	1.76	1.13
aluminum	4	1.75	1.20
vinyl	117	1.61	1.00
steel	9	1.62	1.50
solid wood	48	1.00	1.00
stucco	7	.92	.86
wood composite	8	.74	.85
Total	**250**	**1.58**	**1.00**

Aesthetics

The Aesthetics category captured all manufacturer claims of product beauty, desired looks, curb appeal or attractive exterior. Examples from manufacturer promotional literature include "*beauty,*" "*fewer seams,*" and "*wood-like appearance.*" All manufacturers except stucco strongly promote the aesthetics feature. Wood composite, steel, aluminum, and vinyl promoted aesthetics the most. Wood composite manufacturers promote their siding as having aesthetic appeal similar to natural wood. Aluminum and steel are sometimes considered less attractive for residential siding which could explain increased promotion of the aesthetic value of aluminum/steel siding. Stucco manufacturers promoted aesthetics the least, choosing instead to emphasize attributes unrelated to appearance, such as design flexibility, quality and code approval.

Siding material	N	Mean Freq per Page	Median
wood composite	8	1.69	1.3
steel	9	1.61	1.1
aluminum	4	1.59	.9
vinyl	117	1.52	1.0
brick/masonry	40	1.20	1.0
solid wood	48	1.10	1.0
fiber cement	17	.80	.31
stucco	7	.30	.25
Total	**250**	**1.32**	**1.0**

Quality

This feature captures references to quality across all facets of a manufacturer's operations from product quality to quality control in operations. Sample text strings include *"offers a combination of quality and value," "unparalleled product quality,"* and *"Quality you can count on."* Stucco, fiber cement, and aluminum siding producers promoted quality most frequently, followed closely by steel, vinyl and solid wood. Only wood composite siding manufacturers promoted quality infrequently.

Siding material	N	Mean Freq per Page	Median
stucco	7	.77	.67
fiber cement	17	.77	1.00
aluminum	4	.76	.70
brick/masonry	40	.69	.47
steel	9	.67	.50
vinyl	117	.58	.50
solid wood	48	.58	.04
wood composite	8	.19	.00
Total	**250**	**.61**	**.50**

Company/product reputation

The category of company or product reputation was created to capture promotional references that strengthen the legitimacy of a siding manufacturer and its products. Textual references such as "*Many of the nation's most reputable home builders use…*," company history, e.g., "*Since 1891, homebuyers have trusted…*" and *"Consumer focus group testing shows that our texture looks more like painted wood than competitive vinyl sidings*," were captured in the reputation category. Fiber cement siding manufacturers promoted company reputation by far the most, more than twice per page. Vinyl manufacturers also emphasize reputation. The high count of vinyl manufacturers (117 mfr/brands in this study) suggests that vinyl manufacturers attempt to differentiate their product based on reputation. Brick manufacturer promotion emphasized company histories in the brick making business. Steel siding manufacturers did not rely on company reputation as a feature, which may be part of their overall lack of builder focused promotion.

Siding material	N	Mean Freq per Page	Median
fiber cement	17	2.20	3.00
vinyl	117	1.13	.25
brick/masonry	40	.66	.50
aluminum	4	.56	.45
solid wood	48	.40	.00
stucco	7	.33	.17
steel	9	.20	0
wood composite	8	.06	0
Total	**250**	**.87**	**.24**

Warranty

The warranty category captures all text that specifically mentioned product warranties which included both substrate and finish warranty text. Promotional text such as "*Lifetime Limited Transferable Warranty"* and "*lowest warranty claims in the industry*" were included in the warranty category. Wood composite siding manufacturers promoted warranty most often, possibly to counteract older (1990's and prior) Class Action lawsuits involving wood composite siding material.[21] Aluminum manufacturers also promote warranty consistently.

Siding material	N	Mean Freq per Page	Median
wood composite	8	.95	.92
aluminum	4	.82	.50
vinyl	117	.69	.50
steel	9	.46	.11
fiber cement	17	.40	0
solid wood	48	.40	0
stucco	7	.27	0
brick/masonry	40	.21	0
Total	**250**	**.53**	**.25**

Cost effectiveness

Cost effectiveness can be viewed as an additive function that captures the total cost of purchase, installation and disposal of a siding product. For example, factors that are included in cost effectiveness are purchase cost, the installation cost (labor skill level, amount and pay rate, etc.), product waste generated, life maintenance costs and the cost of product removal and disposal. Promotional text examples of cost effectiveness are "*for a fraction of the cost," "less waste"* and *"The result is a more comfortable home all year long that will produce significant savings on energy bills."* Fiber cement, solid wood, wood composite and steel manufacturers promoted cost effectiveness of their siding products most often, approximately once every 2 pages. Fiber cement products have been able to capture a premium on the marketplace and therefore part of their promotional strategy may be to highlight value. Wood composite siding producers emphasize their cost competitiveness versus solid wood alternatives.

Siding material	N	Mean Freq per Page	Median
fiber cement	17	.63	1.00
solid wood	48	.62	.17
wood composite	8	.59	.63
steel	9	.51	.44
brick/masonry	40	.39	.00
vinyl	117	.34	.13
stucco	7	.30	.20
aluminum	4	.24	.20
Total	**250**	**.43**	**.13**

[21] Status of various class action lawsuits against wood composite siding manufacturers can be found at http://www.sidingsolutions.com/pages/classtat.htm. Some lawsuits are pending while others have been settled.

Ease of maintenance

Siding material	N	Mean Freq per Page	Median
vinyl	117	.45	.33
aluminum	4	.39	.39
fiber cement	17	.34	.06
brick/masonry	40	.28	0
stucco	7	.27	.14
wood composite	8	.17	.03
solid wood	48	.17	0
steel	9	.16	0
Total	**250**	**.34**	0

Siding products that require low maintenance or care after being installed offer the feature/benefit of low maintenance. Promotional text such as *"low maintenance," "a virtually maintenance free home,"* and *"Your home can retain that freshly painted look with an occasional rinse with a garden hose"* were coded in the easy to maintain category. Vinyl and aluminum siding producers promoted the feature/benefit of easy to maintain most frequently. Steel and solid wood mentioned easy to maintain the least. Steel will present the maintenance problem of rusting if not properly coated and sealed. A maintenance issue also exists for solid wood products if the wood isn't a durable species (e.g. cedar) or isn't properly protected. Even with durable species wood may demonstrate notable weathering over time.

Full product line offered

Siding material	N	Mean Freq per Page	Median
fiber cement	17	.67	1.00
vinyl	117	.52	.24
aluminum	4	.49	.40
solid wood	48	.25	0
brick/masonry	40	.15	0
stucco	7	.14	0
steel	9	.07	0
wood composite	8	.06	0
Total	**250**	**.37**	0

The feature/benefit of a full product line is defined as an offering of materials that completely finishes the exterior of a house. In many instances, a full line includes such items as siding trim boards, soffits, drip channel, mounting blocks for outdoor lighting fixtures, etc. Textual references that were categorized within the full product line category were *"extensive collection of integrated accessories," "color-matched trim and accessories,"* and *"…brand vinyl siding, soffit, accessories and skirting."* Fiber cement promoted a full product line the most, followed by vinyl and aluminum. Vinyl and fiber cement manufacturers promoted a fully-appointed exterior with complete trim kits and accessories. Brick manufacturers generally stated that full lines of brick materials were available; however, a full line to brick manufacturers primarily involved color and brick texture variety.

Durability

Product durability is a material's resistance to failure over a long period of time. Durability can be viewed as a multiplicative function that includes such factors as temperature resistance, weather resistance, moisture resistance, air resistance and UV resistance. Textual examples that were coded in the durability category were *"Durable .044" panel thickness," "durability for years to come"* and *"long lasting."* Wood composite, aluminum, and solid wood siding producers promoted product durability the most frequently. Fiber cement siding manufacturers promoted durability the least. Aluminum and solid wood sidings have existed in the marketplace for over 50 years and that may reflect the emphasis on durability for both product categories.

Siding material	N	Mean Freq per Page	Median
wood composite	8	.67	.37
aluminum	4	.44	.49
solid wood	48	.43	0
steel	9	.38	0
stucco	7	.27	.14
brick/masonry	40	.25	0
vinyl	117	.25	0
fiber cement	17	.14	0
Total	**250**	**.30**	0

Technological savvy

This category captures manufacturer references to technology either as a company or as used to manufacture, develop or support product delivery. Also references to innovation or state-of-the-art processes are included in the category. For example, *"Our CI program has become a vehicle for quick response to market demands and new product introduction,"* and *"…manufactured in our two modern plants and fired with natural gas."* Vinyl siding producers promote technological savvy most often, frequently citing new color and scratch resistance technologies. Brick manufacturers promote state-of-the-art facilities, and aluminum siding producers promote technologically advanced finishes. Fiber cement, solid wood and wood composite siding seldom promote technological savvy.

Siding material	N	Mean Freq per Page	Median
vinyl	117	.50	.13
brick/masonry	40	.36	0
aluminum	4	.34	.10
stucco	7	.23	.07
steel	9	.22	0
wood composite	8	.17	0
solid wood	48	.13	0
fiber cement	17	.06	0
Total	**250**	**.35**	0

Ease of installation

A siding product that is easy to install will not require specialized labor, unique tools or time consuming installation techniques. In addition, the product's physical properties will at a minimum not impede installation and at best will help facilitate faster/better installation. Textual references such as "*easy to install,*" "*workability*" and "*Light weight means easier handling, lower shipping costs, easier installation*" were categorized as easy to install. Wood composite siding manufacturers mentioned ease of installation most often, more than twice as often as any other siding category, and heavily promote ease of installation as a feature of wood composite siding. Wood composite manufacturers advertised that their products were easy to cut, pre-assembled, easy to nail and paint. Aluminum and fiber cement siding promoted ease of installation the least.

Siding material	N	Mean Freq per Page	Median
wood composite	8	1.41	1.12
steel	9	.55	.50
solid wood	48	.47	0
stucco	7	.36	0
vinyl	117	.26	0
brick/masonry	40	.25	0
fiber cement	17	.08	0
aluminum	4	0	0
Total	**250**	**.34**	0

Strength

Product strength is a material's resistance to force. Strength for siding products generally consists of strengthening the wall system. Promotional text such as "*strong*" and "*duralock post-formed design*" were coded as product strength. Steel siding manufacturers promoted product strength by far the most frequently. Vinyl manufacturers promoted vinyl thickness as a source of strength and rigidity on the wall.

Siding material	N	Mean Freq per Page	Median
steel	9	1.04	.50
vinyl	117	.44	.04
wood composite	8	.22	.06
fiber cement	17	.16	0
solid wood	48	.06	0
brick/masonry	40	.06	0
aluminum	4	.05	0
stucco	7	.04	0
Total	**250**	**.28**	0

Product integrity

Product integrity is a category that was created to capture manufacturer references to product quality, properties and product workmanship. Text examples of product integrity are *"most tightly quality-coordinated manufacturing and paint finishing process in the industry," "consistency," and "made with only the very best materials."* Solid wood and aluminum promoted product integrity the most. Steel and wood composite promoted product integrity the least. Aluminum manufacturers promoted product quality and color consistency—perhaps to combat color fading and chalking issues. The stucco literature mentioned product performance capabilities and product testing results. Stucco promotional literature was primarily geared toward the architectural/engineering audience of commercial construction.

Siding material	N	Mean Freq per Page	Median
aluminum	4	.34	.10
solid wood	48	.34	0
vinyl	117	.33	0
fiber cement	17	.22	0
stucco	7	.16	.14
brick/masonry	40	.15	0
steel	9	.09	0
wood composite	8	.08	0
Total	**250**	**.28**	0

Weather resistance

A material is weather resistant if it is able to preserve its integrity through typical changes in the exterior environment such as shifts in temperature, changes in moisture and changes in wind. Weather resistance can also be viewed as a multiplicative function involving the aforementioned factors. For example, if a material fails with one condition then overall weather resistance fails. The promotional lines "*best weather protection available,*" "*withstand rain, wind, snow and hail,*" and "*weather-tight protection from the elements*" were included in the weather resistance category. Steel siding manufacturers promoted weather resistance the most often. Steel manufacturers have focused on overall weather resistance while other manufacturers mentioned specific facets of weather resistance.

Siding material	N	Mean Freq per Page	Median
steel	9	.48	.33
vinyl	117	.24	0
wood composite	8	.17	0
stucco	7	.14	0
solid wood	48	.10	0
aluminum	4	.10	0
brick/masonry	40	.05	0
fiber cement	17	.02	0
Total	**250**	**.17**	0

Code approval

This category captured the number of third party references used by manufacturers to bolster the presentation of their products. Text referencing legitimate third parties such as *ASTM*, *Good Housekeeping*, *ISO 9000*, *association approved* or *building code approval* were tallied in this category. Stucco and steel manufacturers promoted their Code approval status most often, approximately once every 2 pages. Aluminum and fiber cement manufacturers seldom promote code approval. Sample text strings include “*Test in accordance with ASTM D5206*” and “*exceed tough ASTM International requirements for quality, durability and consistency.*” Code approval / certification is mentioned more frequently in Web sites and product brochures (Mean=.314) than in magazine ads (mean=.06).

Siding material	**N**	**Mean Freq per Page**	**Median**
stucco	7	.53	.29
steel	9	.46	.50
vinyl	117	.25	0
solid wood	48	.20	0
wood composite	8	.17	0
brick/masonry	40	.14	0
fiber cement	17	.10	0
aluminum	4	.10	0
Total	**250**	**.23**	0

Wind resistance

A product that resists damage from strong winds is considered wind resistant. Some products have failed in high wind situations either by blowing off the wall, by lifting at seams, or by failure around fasteners. Typically hurricanes cause the most problems with wind related siding failures. Examples of wind resistant promotions are “*wind resistant up to 210 mph,” “Single-strength nail hem for strength against winds up to 114 mph,”* and *“Rigidform 135 technology has been tested to withstand wind load pressures up to 135 mph.”* Vinyl manufacturers are addressing past failures where thinner gauge vinyl didn’t withstand strong winds. Failure generally occurred at the nailing hem. Currently vinyl manufacturers are promoting a thicker/stronger nailing hem to resist strong winds. Vinyl manufacturers are the most specific when listing the wind speeds that their products can withstand.

Siding material	**N**	**Mean Freq per Page**	**Median**
vinyl	117	.34	0
steel	9	.19	0
solid wood	48	.03	0
fiber cement	17	.02	0
brick/masonry	40	.01	0
wood composite	8	0	0
aluminum	4	0	0
stucco	7	0	0
Total	**250**	**.17**	0

Sun resistance

Sun resistance is a product's ability to preserve its integrity and appearance when exposed to sunlight—particularly ultra violet radiation. Just as paper can yellow or fade when exposed to sunlight over time, siding products and paint coating can have a similar fate. Promotional text examples like "*fade resistant,*" "*UV-resistant,*" and "*UV-protected*" were categorized as sun resistant. Sun resistance was not a heavily promoted feature. Vinyl and aluminum promoted sun resistance the most while stucco and wood composite siding did not promote sun resistance at all. Vinyl manufacturers have had problems in the past with colors fading when exposed to sun over time, especially with darker colors, and thus current promotional efforts highlight new non-fade vinyl formulations. Brick manufacturers promoted that brick gains character when exposed to the sun and elements over time. Wood composite and solid wood manufacturers typically rely on paint and coatings that are adversely affected by sunlight.

Siding material	N	Mean Freq per Page	Median
vinyl	117	.33	0
aluminum	4	.29	.29
steel	9	.06	0
solid wood	48	.04	0
brick/masonry	40	.03	0
fiber cement	17	.01	0
wood composite	8	0	0
stucco	7	0	0
Total	**250**	**.18**	0

Customer service excellence

Customer service can be defined as manufacturers' level of service support for their siding products, such as on-call service representatives, product warranties or services that facilitate product usage. Textual examples that were tagged as representing excellent customer service were "*excellent customer service,*" and "*differentiates itself from competitors through superior customer service, technical support.*" Brick and stucco most often touted customer service, followed by solid wood. Brick manufacturers advertised available design services for their products as well as superior customer service. Stucco manufacturers promoted customer consultation and service.

Siding material	N	Mean Freq per Page	Median
brick/masonry	40	.34	0
stucco	7	.29	.14
solid wood	48	.24	0
steel	9	.13	0
vinyl	117	.12	0
fiber cement	17	.11	0
wood composite	8	.08	0
aluminum	4	.05	0
Total	**250**	**.18**	0

Moisture resistance

Moisture resistance is a material's ability to be unaffected by moisture through adsorption or absorption. A siding material must establish an impermeable barrier between the house exterior and interior. Promotional text examples of moisture resistance are *"high impermeability to liquids,"* *"moisture resistant,"* and *"a tighter seal, helping to keep rain, wind and assorted creatures outside."* Steel siding producers claimed moisture resistance the most frequently.

Siding material	N	Mean Freq per Page	Median
steel	9	.44	0
fiber cement	17	.25	0
wood composite	8	.22	0
solid wood	48	.20	0
stucco	7	.10	0
vinyl	117	.10	0
aluminum	4	.05	0
brick/masonry	40	.04	0
Total	**250**	**.13**	0

Impact resistance

An impact resistant material has a hard surface which resists denting, splitting or scratching when it comes into contact with other materials. Impact resistance for a siding material is important for normal use such as children playing, objects ejected from lawn mover blades, etc. In addition, during the construction process it is helpful to have a siding material that resists job-site abuse. Very little emphasis was given to impact resistance in promotional materials. Text examples of impact resistance include *"resists hail, dents and dings,"* and *"Premium .044" thickness ensures outstanding impact resistance."* Vinyl and steel siding promoted impact resistance minimally while other siding materials seldom promoted it. Vinyl siding has promoted impact resistance in the past to overcome perceived problems such as splitting and shattering in cold weather if impacted by other materials.

Siding material	N	Mean Freq per Page	Median
vinyl	117	.19	0
steel	9	.13	0
stucco	7	.04	0
wood composite	8	.02	0
fiber cement	17	.02	0
brick/masonry	40	.01	0
solid wood	48	0	0
aluminum	4	0	0
Total	**250**	**.10**	0

Dimensional stability

Promotion of dimensional stability included text strings that infer that the product doesn't change shape or size. Dimensional stability can be challenged by temperature change (mostly vinyl) or changes in moisture (wood products). Sample promotional text strings are *"will not warp,"* and *"won't sag or bow."* Solid wood and wood composite siding producers promote dimensional stability more than any other siding producers. Other siding manufacturers promote it very little, if at all.

Siding material	N	Mean Freq per Page	Median
solid wood	48	.41	0
wood composite	8	.27	.25
fiber cement	17	.12	0
vinyl	117	.04	0
brick/masonry	40	.01	0
aluminum	4	.00	0
stucco	7	.00	0
steel	9	.00	0
Total	**250**	**.12**	0

Insect and mold resistance

A desirable feature of a building material is resistance to insect infestation/consumption and to fungi/mold. Issues with termites and mold can be significant problems facing some communities. For example, in Louisiana termites attacking wood frame construction have triggered considerable attention from code inspectors—some even arguing the banning of wood materials (cite). Mold is another problem with housing and some occupants have attributed serious illnesses to mold (cite). Promotional text such as "*Resistant to termites/pests,*" *"mold resistant"* and *"decay resistant"* was included in the insect and mold resistance category. Wood composite siding producers promoted insect and mold resistance most often perhaps to address consumer perception regarding termite and mold problems associated with wood products.

Siding material	N	Mean Freq per Page	Median
wood composite	8	.24	0
solid wood	48	.19	0
steel	9	.19	0
stucco	7	.14	0
fiber cement	17	.12	0
vinyl	117	.07	0
brick/masonry	40	.03	0
aluminum	4	0	0
Total	**250**	**.10**	0

Performance in extreme conditions

Siding material	N	Mean Freq per Page	Median
fiber cement	17	.55	0
steel	9	.22	0
aluminum	4	.14	0
stucco	7	.14	0
solid wood	48	.10	0
brick/masonry	40	.08	0
vinyl	117	.05	0
wood composite	8	.04	0
Total	**250**	**.10**	0

A product that withstands extreme natural events such as wildfires, earthquakes and hurricanes is classified as performing in extreme conditions. Manufacturer text such as *"fire treated," "hurricane-ready,"* and *"Class A, non-combustible"* were tagged as able to perform in extreme conditions. Fiber cement siding producers promoted extreme performance the most, about once every 2 pages. Other siding producers seldom promoted performance in extreme conditions. Fiber cement has been marketed heavily in the west and southwest. These regions have experienced numerous extreme weather events over the years. Steel benefits from promoting its extreme performance characteristics given its non-combustible nature and high strength capabilities.

Temperature resistance

Siding material	N	Mean Freq per Page	Median
aluminum	4	.19	.10
vinyl	117	.09	0
wood composite	8	.04	0
brick/masonry	40	.02	0
fiber cement	17	.02	0
solid wood	48	.01	0
stucco	7	0	0
steel	9	0	0
Total	**250**	**.05**	0

A material is resistant to temperature if the material is able to preserve its integrity (shape, appearance, properties, etc.) within the temperature range of the exterior environment. Examples of promotional text that was categorized as temperature resistant include *"will endure sub-freezing cold, will withstand blistering heat," "will resist temperature extremes,"* and *"superior freeze thaw protection."* Aluminum promoted temperature resistance the most often; other siding classifications promoted it minimally if at all. Aluminum manufacturers promote the temperature resistance of aluminum versus other alternative such as vinyl—which in the past has had problems with thermal expansion when heated by the sun. Temperature resistance may not be a highly sought after feature/benefit.

Energy efficiency

A siding material is considered energy efficient if it improves the overall thermal properties of a wall system. In most instances energy efficiency is achieved through an increased thermal conductivity resistance value. Textual examples of energy efficiency are *"insulating capabilities and passive solar heat retention make brick equally suitable for southern summers and northern winters," "energy efficiency,"* and *"energy savings."* Solid wood and vinyl producers promoted energy efficiency the most , although no manufacturers heavily promote energy efficiency.

Siding material	N	Mean Freq per Page	Median
solid wood	48	.15	0
vinyl	117	.15	0
stucco	7	.15	0
brick/masonry	40	.08	0
aluminum	4	.05	0
steel	9	.03	0
wood composite	8	0	0
fiber cement	17	0	0
Total	**250**	**.12**	0

Availability

The Availability feature was used to describe manufacturer promotion of product accessibility to builders. Availability was seldom promoted for siding. Manufacturer text such as "*readily available,*" and "*Our seventeen production facilities manufacture more than one billion bricks a year, and are located in key distribution areas within easy access to any building project in North America*." were coded as readily available. Very few manufacturers promoted the Availability feature, perhaps because manufacturers supply distributors and leave it up to the distributors to ensure that demand is met. Brick manufacturers promoted availability on average .14 times per page, or about once every 8 pages.

Siding material	N	Mean Freq per Page	Median
brick/masonry	40	.14	0
solid wood	48	.09	0
stucco	7	.05	0
steel	9	.05	0
wood composite	8	.04	0
vinyl	117	.01	0
aluminum	4	0	0
fiber cement	17	0	0
Total	**250**	**.04**	0

Environmental friendliness

This category captures any references to the "greenness" of a product or the environmental benefits a product provides such as less waste or sustainable harvest. Sample strings are *"factory pollution control,"* and "*products will yield an environmentally and financially responsible 67% less scrap."* Steel siding producers promoted environmental friendliness, while all other siding material categories promoted it seldom, if at all.

Siding material	N	Mean Freq per Page	Median
steel	9	.33	0
solid wood	48	.13	0
wood composite	8	.12	.06
brick/masonry	40	.05	0
stucco	7	.02	0
fiber cement	17	.02	0
vinyl	117	.01	0
aluminum	4	0	0
Total	**250**	**.05**	0

Corrosion resistance

Corrosion resistance is a product's resistance to chemical breakdown when exposed to the natural service environment. Corrosion is particularly pertinent to metal products such as steel (rusting). Text strings tagged with the corrosion resistance benefit included, for example, "*corrosion-resistant, hot-dip aluminum-zinc alloy,*" "*Won't rust, warp, crack or peel,*" and "*No chalk washdown: will not chalk-stain.*" Steel had the most promotion geared toward corrosion resistance, while all other siding material classifications had few, if any, mentions of corrosion resistance.

Siding material	N	Mean Freq per Page	Median
steel	9	.39	0
stucco	7	.04	0
vinyl	117	.02	0
brick/masonry	40	.01	0
wood composite	8	0	0
solid wood	48	0	0
aluminum	4	0	0
fiber cement	17	0	0
Total	**250**	**.03**	0

Deadens sound

This feature includes references to sound insulating properties of siding materials such as "is a great sound insulator," and "The use of CEDARONE for walls and ceilings provides a level of sound insulation that will quieten (sic) rooms." Very few manufacturers promote their product's sound deadening capability.

Siding material	N	Mean Freq per Page	Median
solid wood	48	.035	0
brick/masonry	40	.032	0
vinyl	117	.029	0
wood composite	8	0	0
aluminum	4	0	0
stucco	7	0	0
fiber cement	17	0	0
steel	9	0	0
Total	**250**	**.0265**	0

Non-toxicity

Only 3 brands of siding promoted non-toxicity (2 vinyl, 1 brick). Seemingly, consumer attention to hazardous materials in the home such as past issues with formaldehyde emissions is no longer an issue.

Siding material	N	Mean Freq per Page	Median
brick/masonry	40	.005	0
vinyl	117	.004	0
wood composite	8	0	0
solid wood	48	0	0
aluminum	4	0	0
stucco	7	0	0
fiber cement	17	0	0
steel	9	0	0
Total	**250**	**.00**	0

APPENDIX H – Data tables used for Builder/Manufacturer Gap Analyses

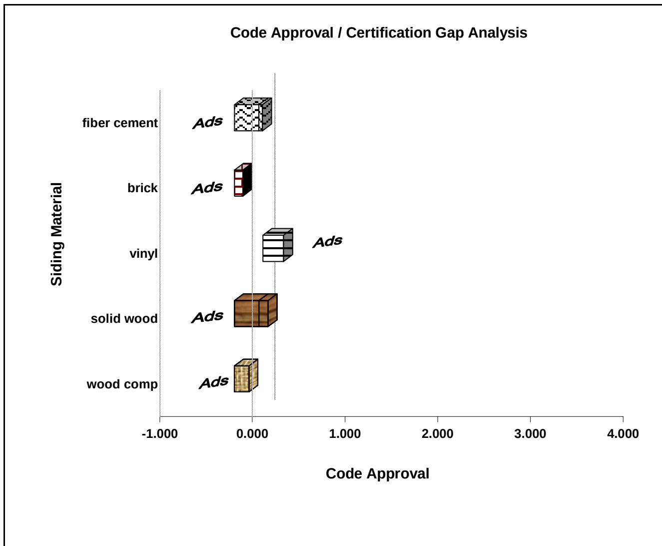
Performance rating (Scale of -5 to +5, where -5 = extremely bad performance, 0=Neutral, +5 = extremely good performance) for the siding materials (2001):

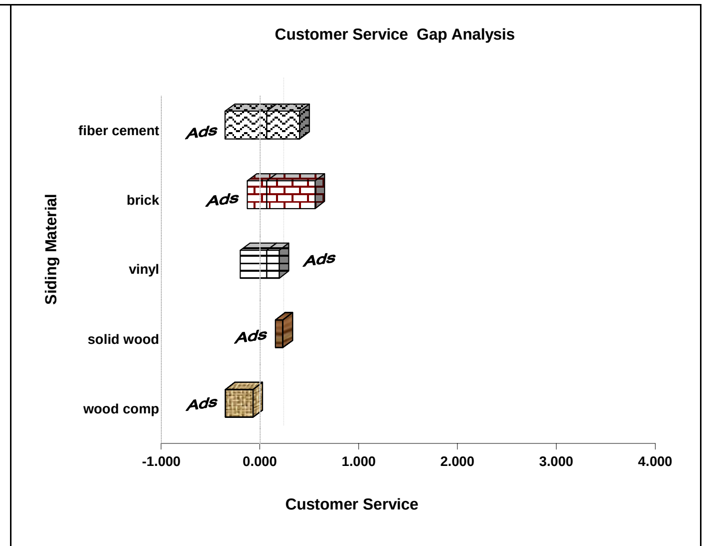
(from file "Backup of Descriptive Analysis (1).doc", GCA)

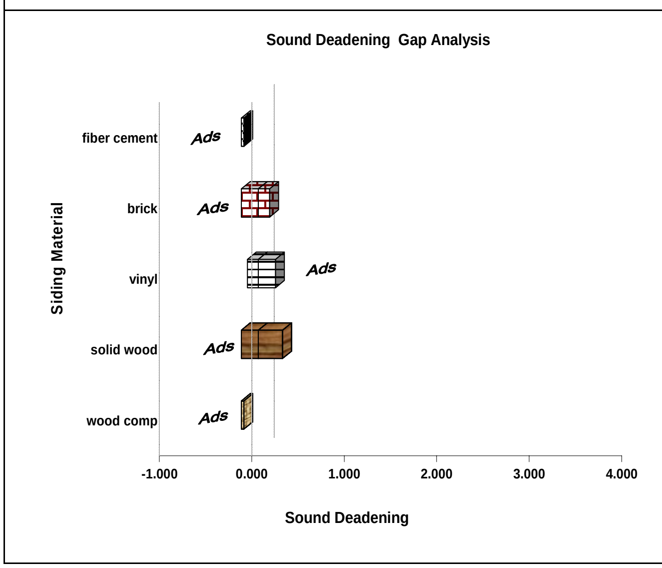
By siding material type:

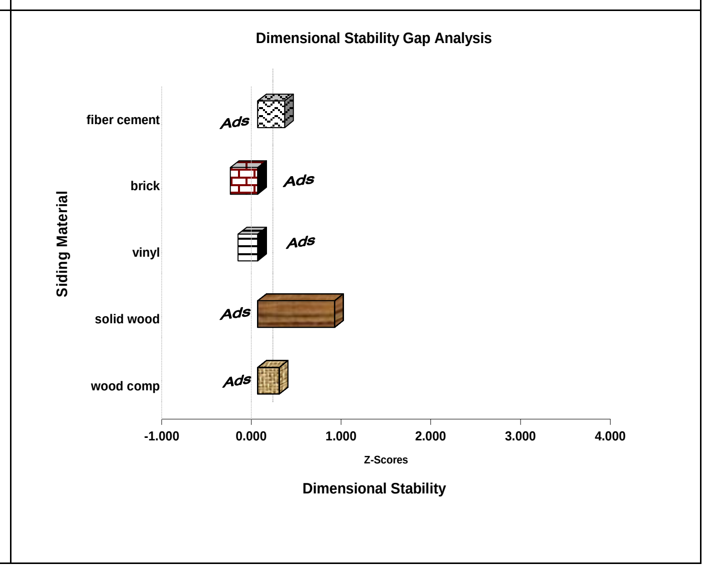
Features	Vinyl (n=83)	Cedar / redwood (n=83)	Aluminum or steel (n=83)	Cement fiber (n=6)	Stucco (n=1)	Brick or stone (n=1)	Hard Board (n=5)	OSB (n=2) →-→	Wood composite (n=7)
Durability or long term performance (n=83)	3.9	3.5	2.8	4.8	2	5	1.0	1.0	1.0
Low maintenance (n=82)	4.1	0.0	3.2	3.0	4	5	-1.8	0	-1.3
Aesthetics (Curb appeal) (n=75)	3.8	1.0	3.5	4.5	3	5	3.4	-0.5	2.3
Damage or impact resistance (n=83)	3.0	0.5	1.2	3.8	2	-2	0.2	2.0	.9
Status or quality image (n=83)	3.3	3.5	1.5	2.8	4	5	3.4	-0.5	2.3
Manufacturers warranty (n=82)	3.9	0.5	2.9	3.5	2	-3.0	1.2	-1.0	.6
Easier to install(n=83)	3.1	-3.0	1.2	-1.2	3	-4.0	0.8	-0.5	.4

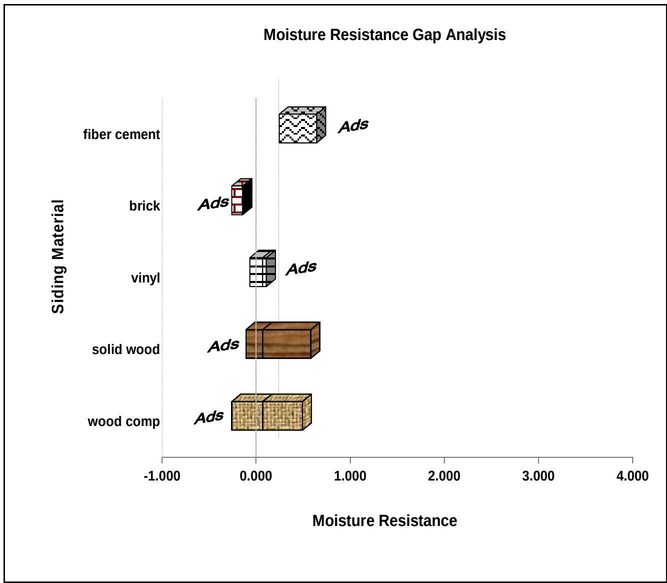
APPENDIX I - Additional Data Charts for Ad vs. Brochure Gap Analysis










Moisture Resistance Gap Analysis
Siding Material
fiber cement
brick
vinyl
solid wood
wood comp
Ads
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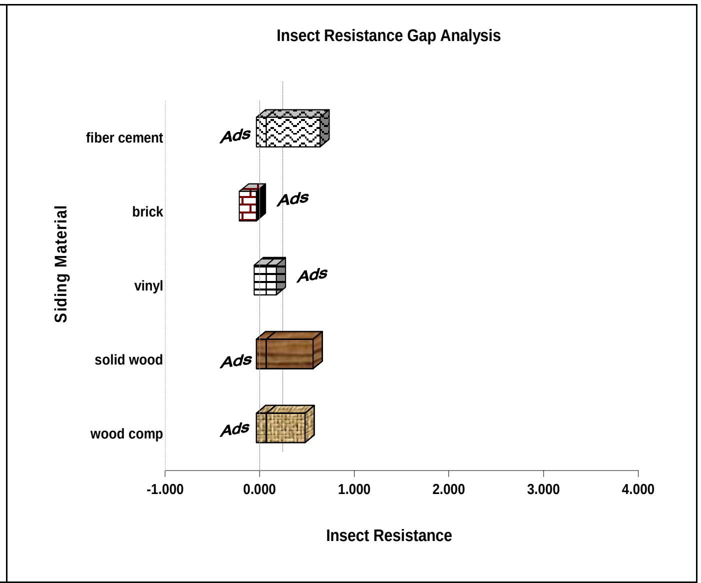
0.000
1.000
2.000
3.000
4.000
Moisture Resistance


Insect Resistance Gap Analysis
Siding Material
fiber cement
brick
vinyl
solid wood
wood comp
Ads
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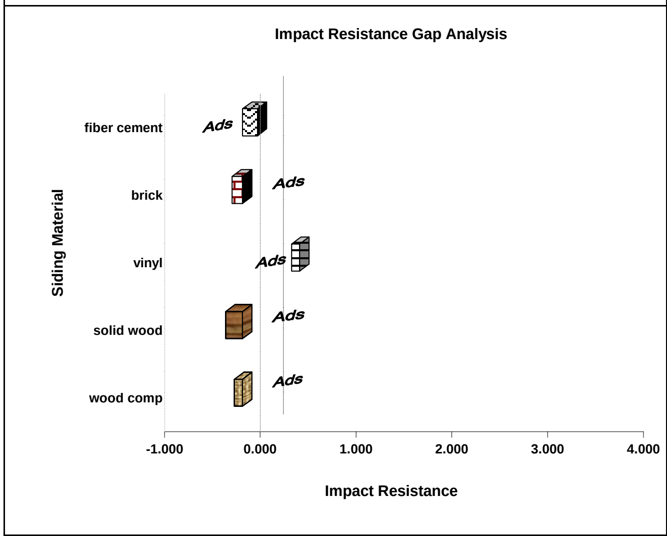
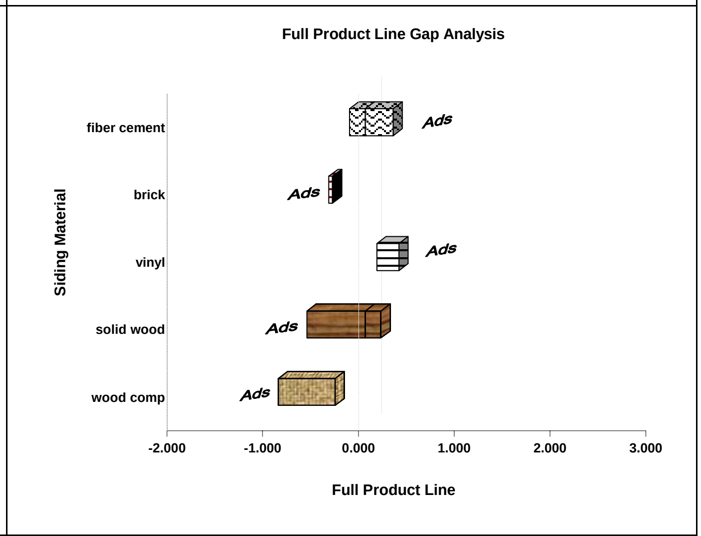
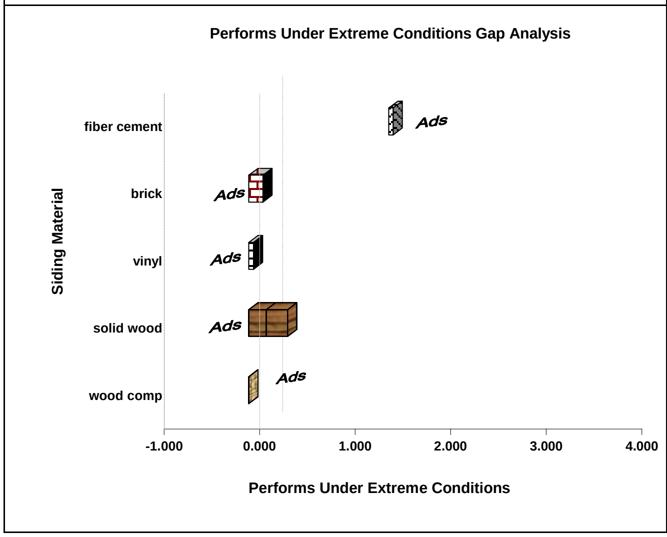
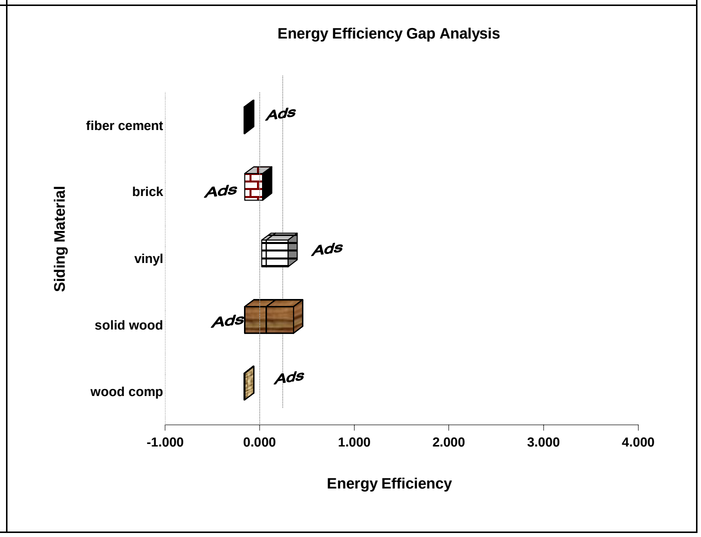
0.000
1.000
2.000
3.000
4.000
Insect Resistance


Impact Resistance Gap Analysis
Siding Material
fiber cement
brick
vinyl
solid wood
wood comp
Ads
-1.000
0.000
1.000
2.000
3.000
4.000
Impact Resistance


Full Product Line Gap Analysis
Siding Material
fiber cement
brick
vinyl
solid wood
wood comp
Ads
-2.000
-1.000
0.000
1.000
2.000
3.000
Full Product Line


Performs Under Extreme Conditions Gap Analysis
Siding Material
fiber cement
brick
vinyl
solid wood
wood comp
Ads
-1.000
0.000
1.000
2.000
3.000
4.000
Performs Under Extreme Conditions


Energy Efficiency Gap Analysis
Siding Material
fiber cement
brick
vinyl
solid wood
wood comp
Ads
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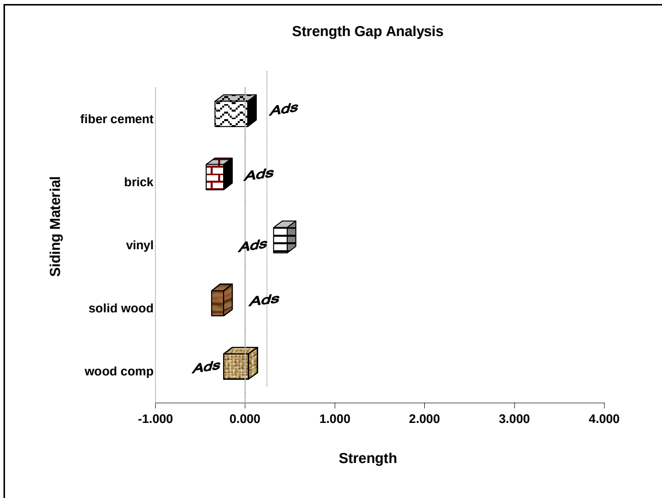
0.000
1.000
2.000
3.000
4.000
Energy Efficiency


Strength Gap Analysis
Siding Material
fiber cement
brick
vinyl
solid wood
wood comp
Ads
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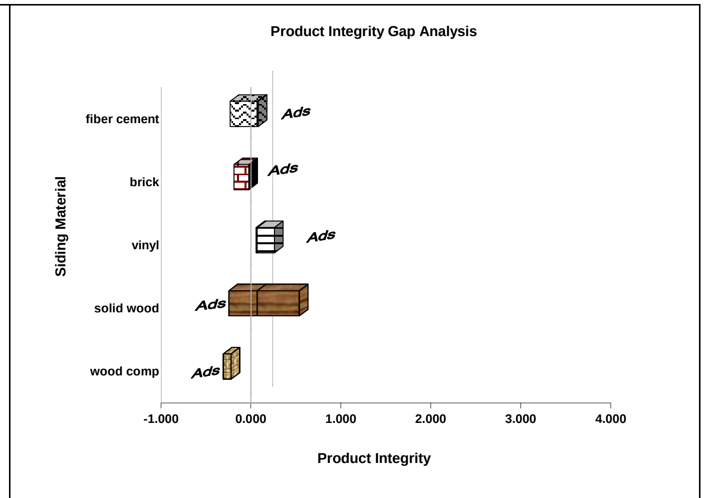
0.000
1.000
2.000
3.000
4.000
Strength


Product Integrity Gap Analysis
Siding Material
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brick
vinyl
solid wood
wood comp
Ads
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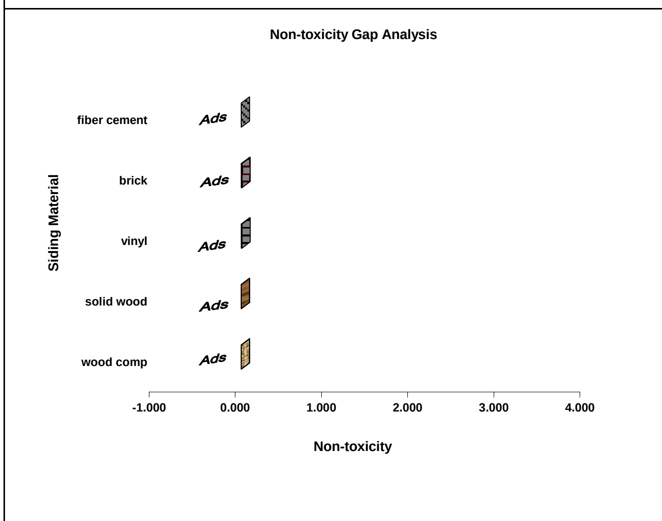
0.000
1.000
2.000
3.000
4.000
Product Integrity


Non-toxicity Gap Analysis
Siding Material
fiber cement
brick
vinyl
solid wood
wood comp
Ads
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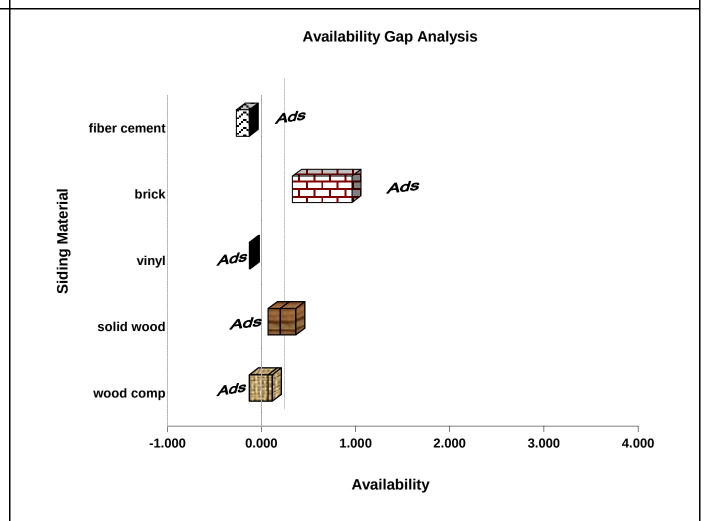
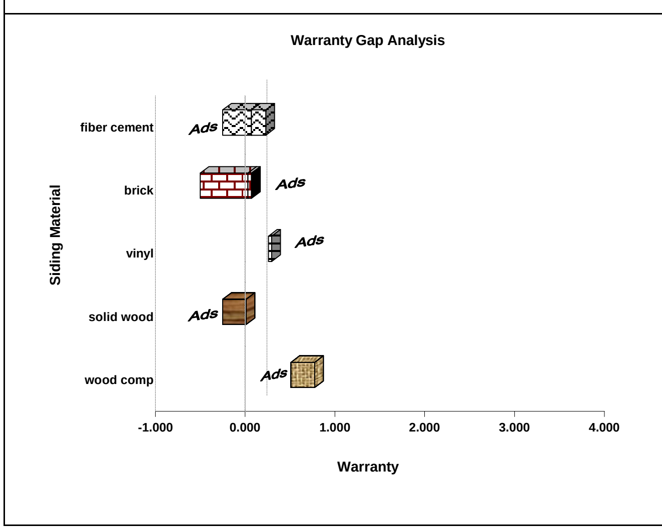
0.000
1.000
2.000
3.000
4.000
Non-toxicity


Availability Gap Analysis
Siding Material
fiber cement
brick
vinyl
solid wood
wood comp
Ads
-1.000
0.000
1.000
2.000
3.000
4.000
Availability


Warranty Gap Analysis
Siding Material
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brick
vinyl
solid wood
wood comp
Ads
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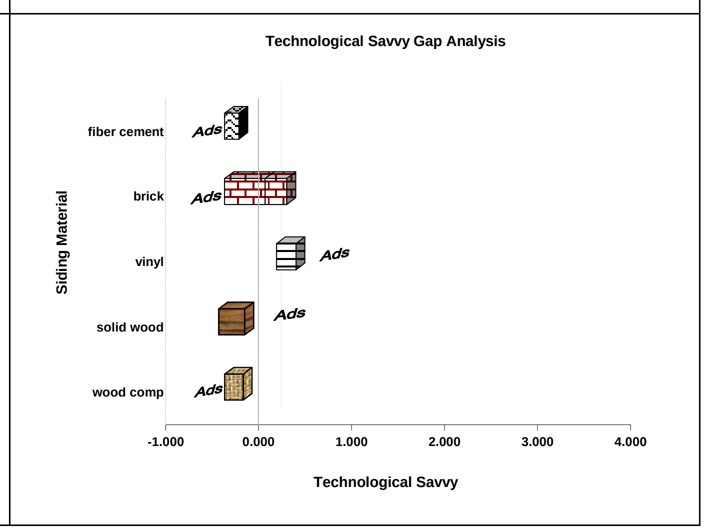
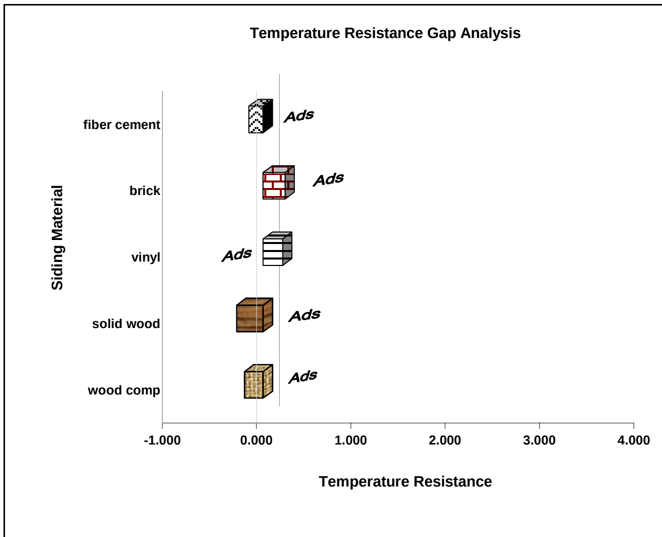
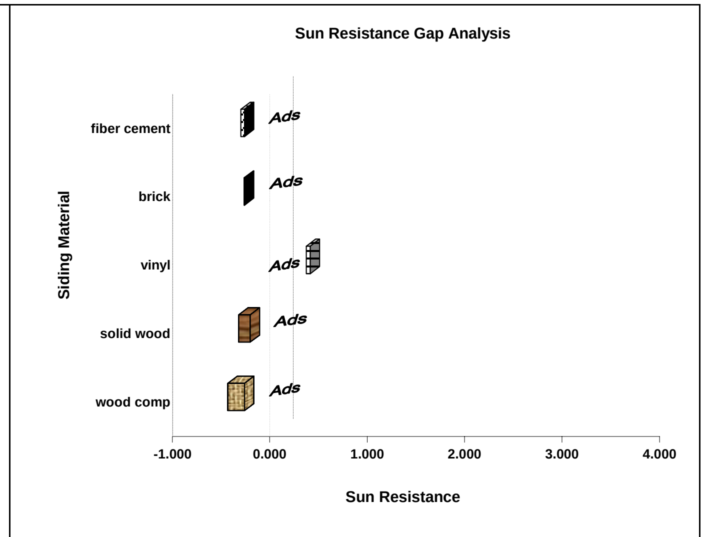
0.000
1.000
2.000
3.000
4.000
Warranty


Technological Savvy Gap Analysis
Siding Material
fiber cement
brick
vinyl
solid wood
wood comp
Ads
-1.000
0.000
1.000
2.000
3.000
4.000
Technological Savvy


Temperature Resistance Gap Analysis
Siding Material
fiber cement
brick
vinyl
solid wood
wood comp
Ads
-1.000
0.000
1.000
2.000
3.000
4.000
Temperature Resistance


Sun Resistance Gap Analysis
Siding Material
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brick
vinyl
solid wood
wood comp
Ads
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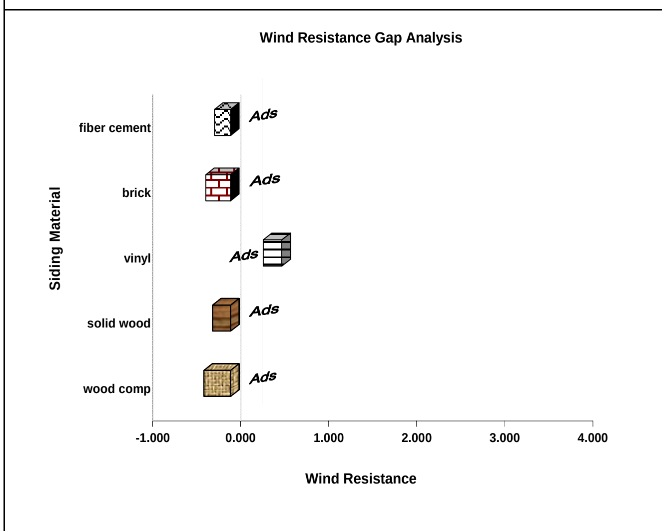
0.000
1.000
2.000
3.000
4.000
Sun Resistance


Wind Resistance Gap Analysis
Siding Material
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brick
vinyl
solid wood
wood comp
Ads
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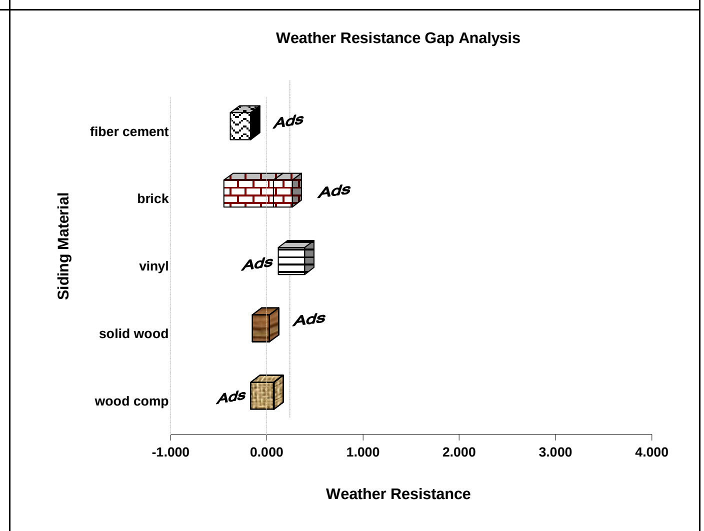
0.000
1.000
2.000
3.000
4.000
Wind Resistance


Weather Resistance Gap Analysis
Siding Material
fiber cement
brick
vinyl
solid wood
wood comp
Ads
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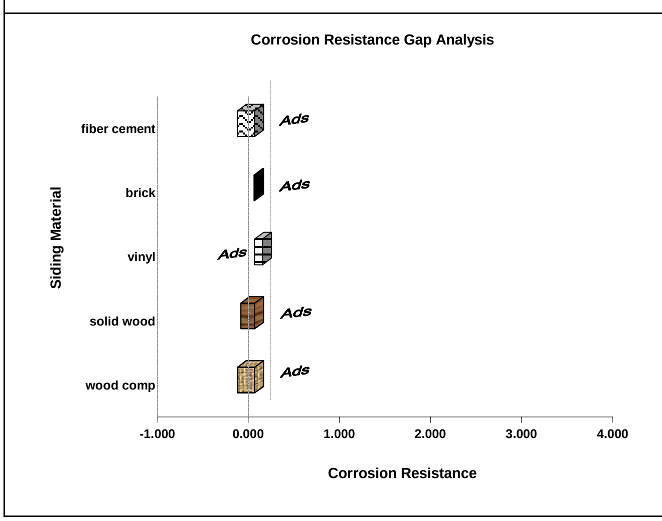
0.000
1.000
2.000
3.000
4.000
Weather Resistance


Corrosion Resistance Gap Analysis
Siding Material
fiber cement
brick
vinyl
solid wood
wood comp
Ads
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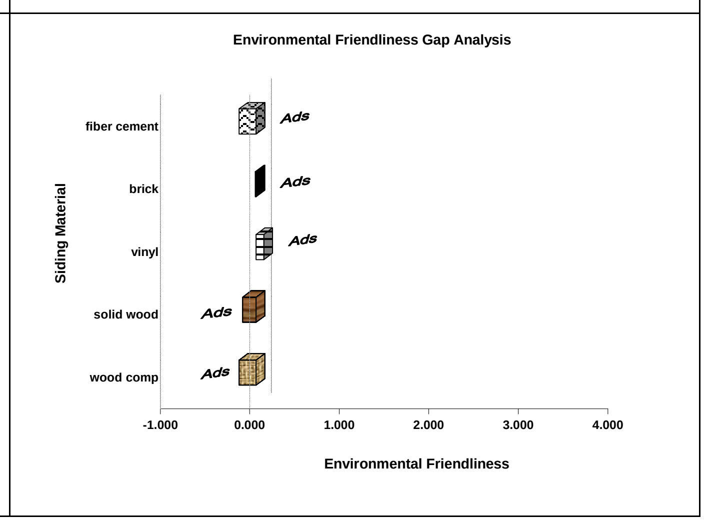
0.000
1.000
2.000
3.000
4.000
Corrosion Resistance


Environmental Friendliness Gap Analysis
Siding Material
fiber cement
brick
vinyl
solid wood
wood comp
Ads
-1.000
0.000
1.000
2.000
3.000
4.000
Environmental Friendliness

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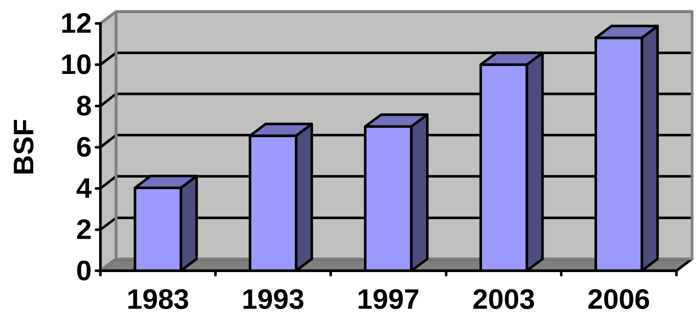


Figure 1 - Annual Sales Volume Trend (BSF), U.S. Residential Siding

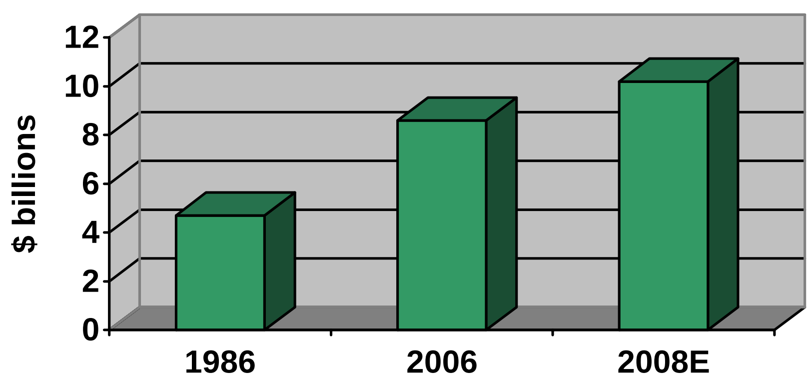
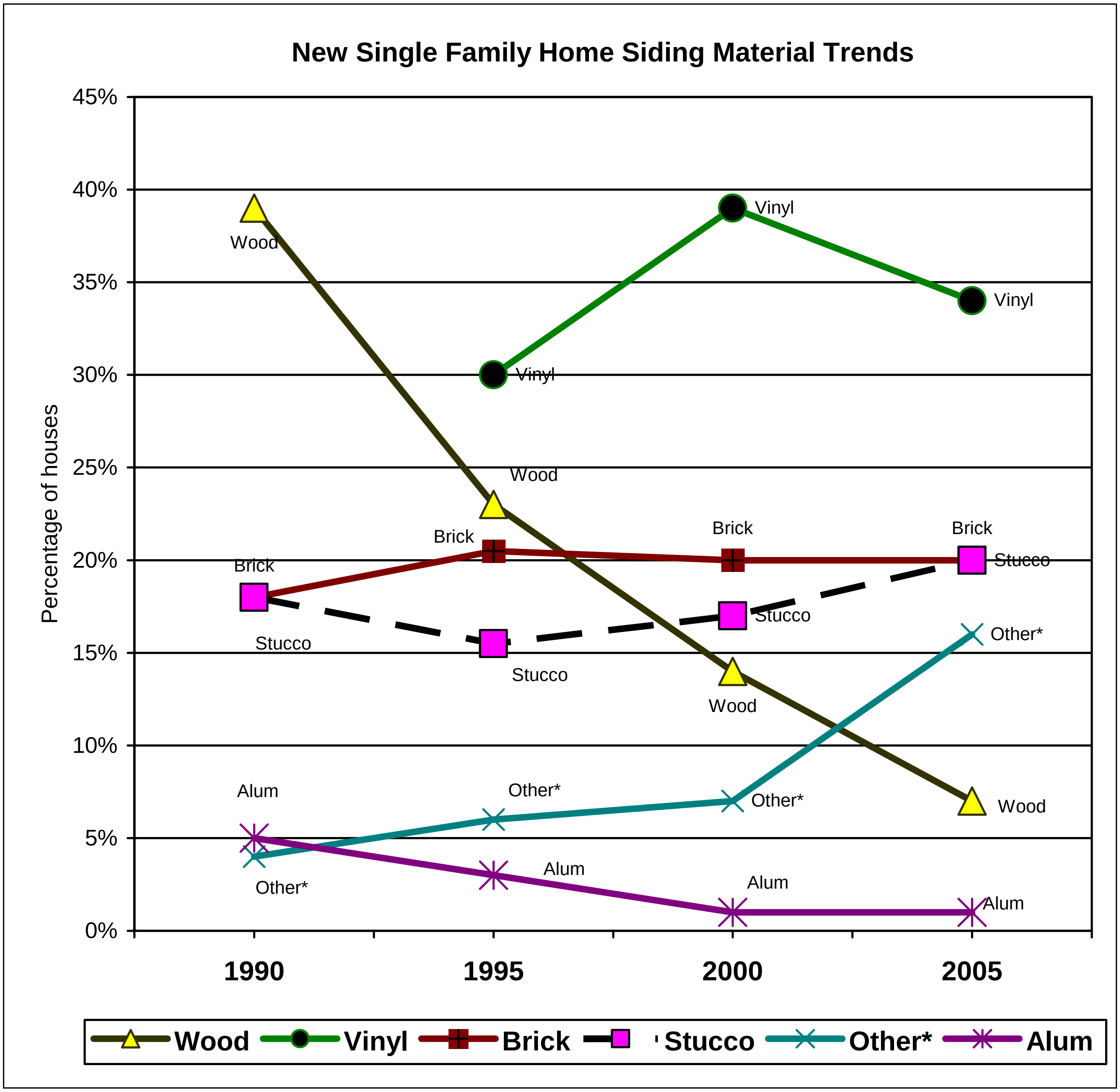


Figure 2 - Annual Sales Trend ($billions), U.S. Residential Siding

Figure 3 - Siding Trends in New Single Family Homes



**Other* category includes cinder block, stone, fiber cement, and others. Prior to 1992, *Other* includes vinyl siding.

Source: All data is from the U.S. Census Bureau, Annual Construction Statistics, Characteristics of New Housing: Principal Type of Exterior Wall Material of New One-Family Homes Completed

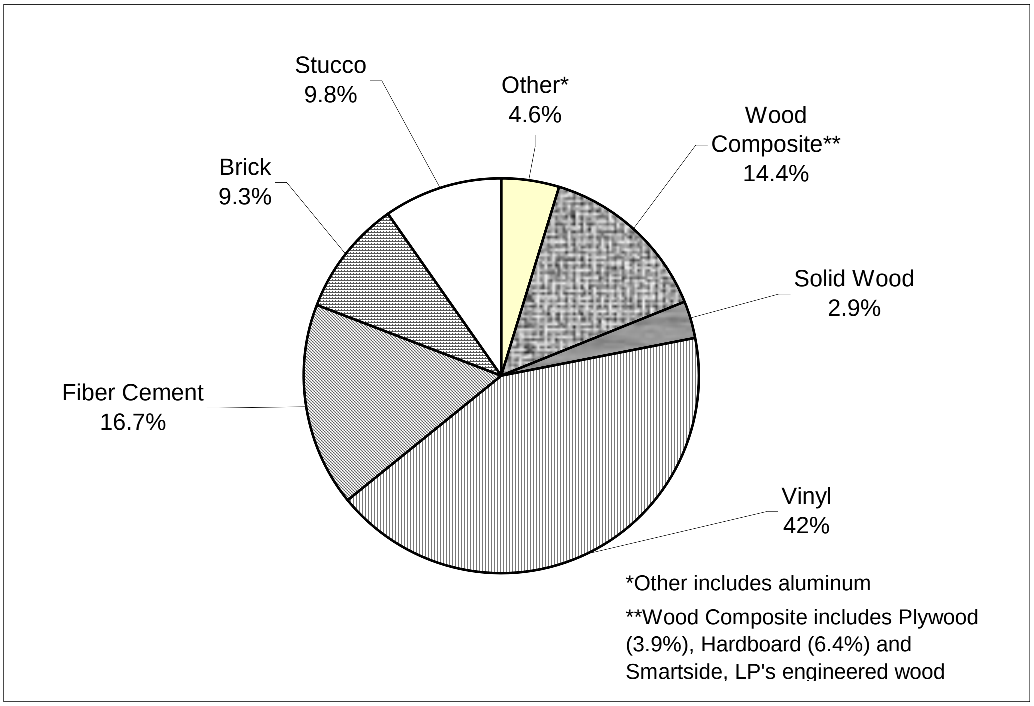


Figure 4 - Louisiana Pacific Corp., 2003 Siding Market Share by Material

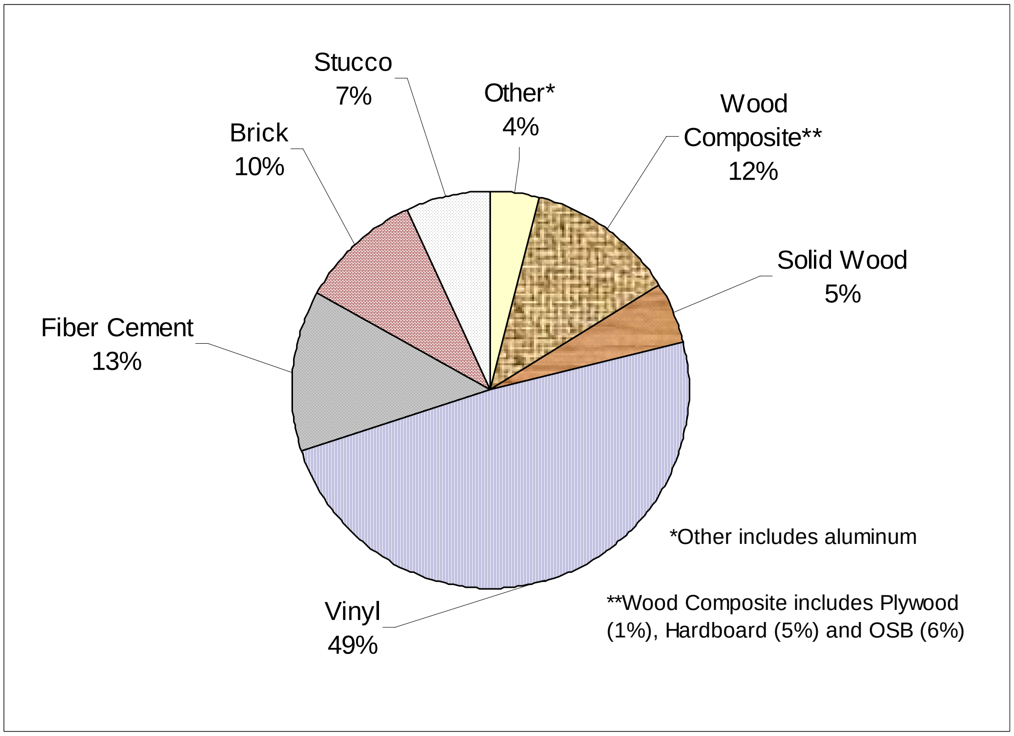


Figure 5 - James Hardie, 2003 Siding Market Share by Material

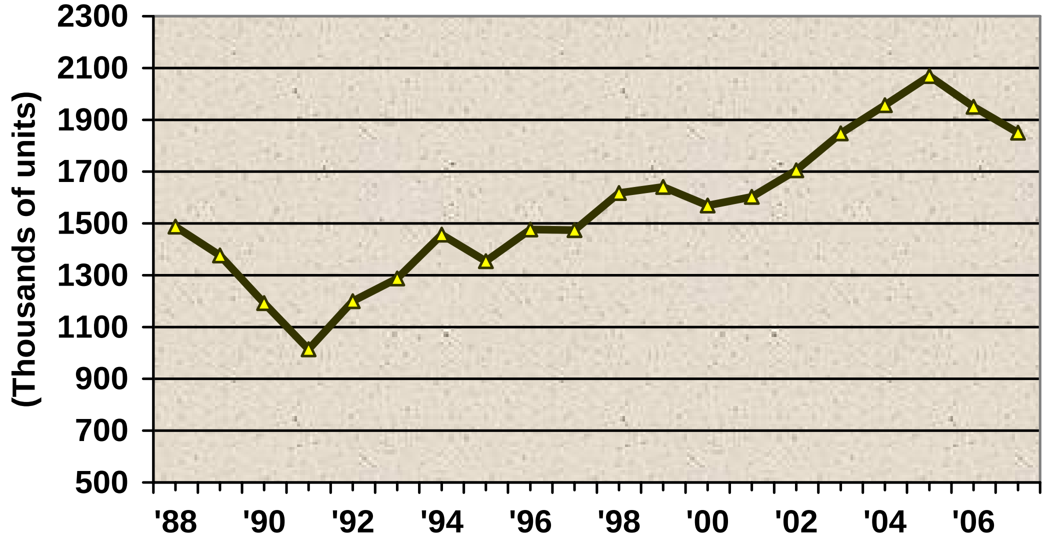


Figure 6 – New U.S. Housing Starts, 1988 - 2006

Source: U.S. Census Bureau, New Privately Owned Housing Units Started, Annual Data

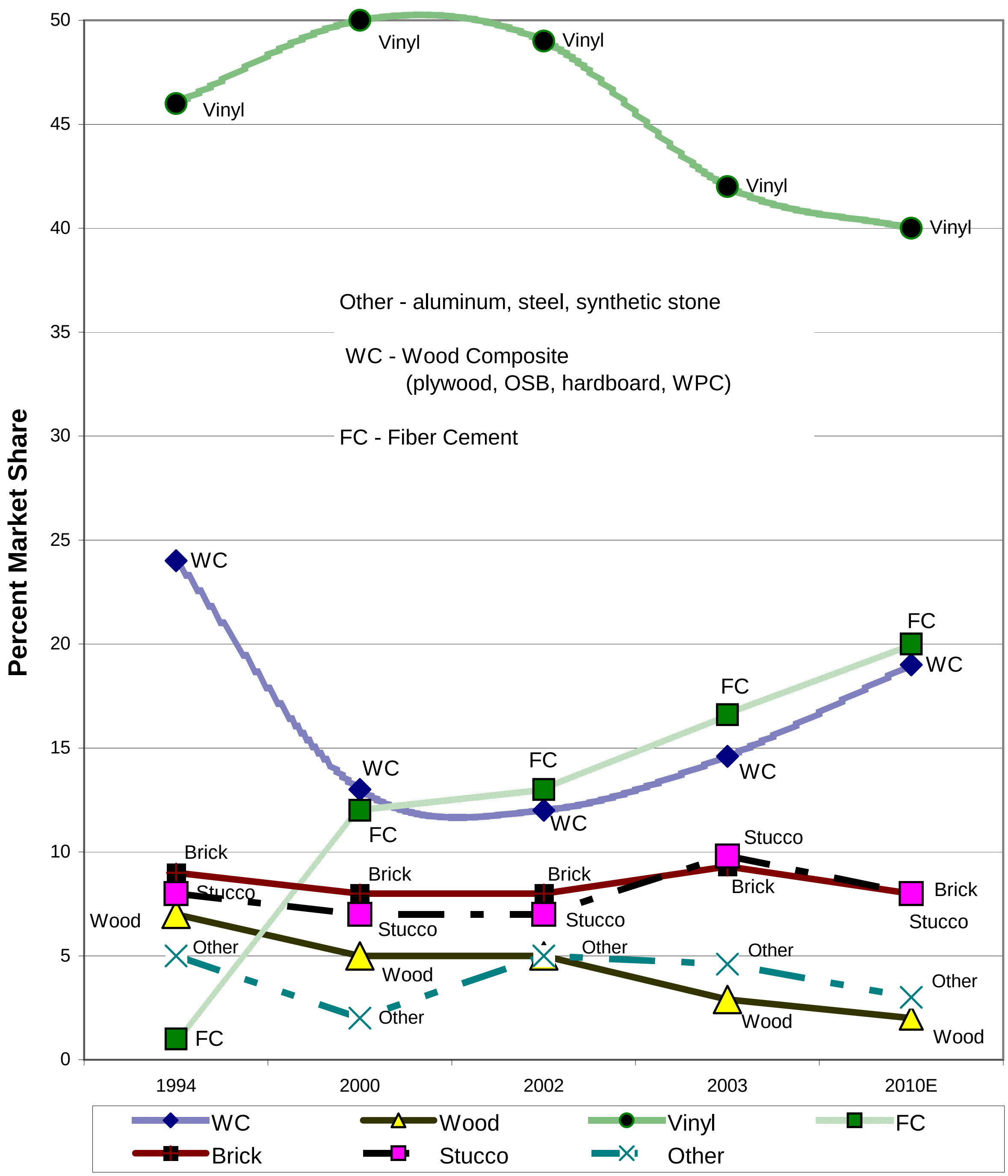


Figure 7 – U.S. residential siding material consumption by type, 1994-2010E

* The 2010 estimate for volume was calculated by using a 1.4% market volume growth rate as predicted by Freedonia.
Sources: James Hardie 2001, 2002 & 2003 Analyst Presentations; Louisiana-Pacific Analyst Presentation 2005

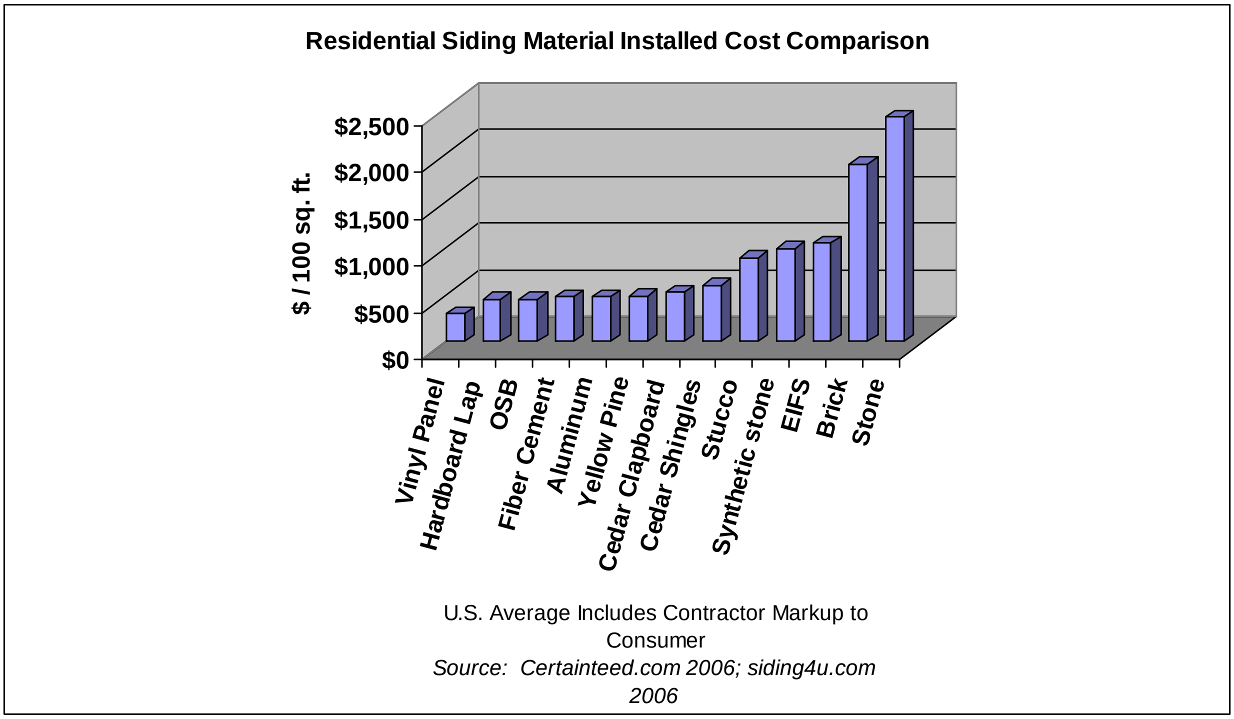


Figure 8 - Siding Installed Cost Comparison

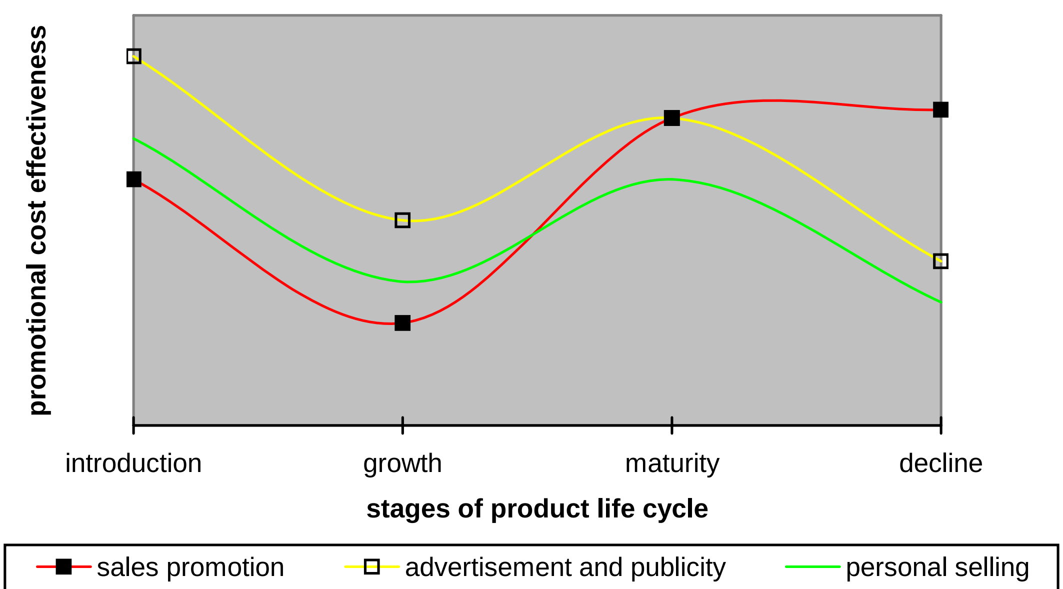


Figure 9 - Cost effectiveness of different promotional tools at different life cycle stages

Source: Kotler (1997, p. 628)

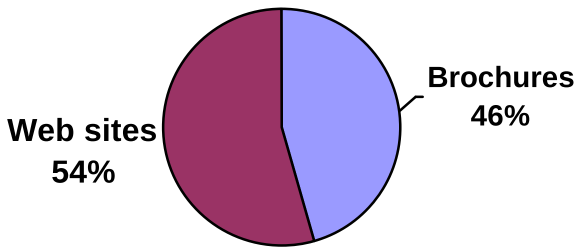


Figure 10 - Product brochure or Web? Sources for 92 manufacturers, 160 brands

Figure 11 - Example Web page – U.S. Steel siding

http://www.ussteel.com/metal/metal/prepainted.shtml

METAL BUILDING, ROOFING, SIDING, AND PURLIN

PRODUCTS

STEELTRACK℠ DEMO

RESIDENTIAL ROOFING

COATED SHEET BASICS

TECHNICAL BULLETINS

EXAMPLE SPECIFICATIONS

PHOTO GALLERY

INDUSTRY LINKS

USS CONSTRUCTION HOME

CONTACT US

Metal Building, Roofing, Siding and Purlin

Products - Prepainted

> Advantages, Benefits

> Roofing

> Building Panels

Exterior and Interior Applications

A fresh and practical approach to architectural and product design

The trend is to steel ... because it makes sense!

Prepainted steel sheet ...now more than ever

Throughout the world, the construction, appliance and various other industries are switching more and more to prepainted steel sheet. In North America alone, there is an ever increasing number of new or upgraded continuous coil painting lines to serve these various industries. In recent years, the markets for prepainted steel sheet have grown to a total of two million tons. These markets include industries that construct buildings of all kinds and manufacture appliances, automotive vehicles, containers, metal cans, air conditioners, and residential roofing.

For a better bottom line...

Usage is increasing dramatically because prepainted steel sheet is so practical and efficient. Prepainted steel sheet is very cost effective for manufacturers of painted sheet steel products. Because it requires no

in-plant painting either before or after fabrication, prepainted steel sheet eliminates the manufacturer's capital burden for paint facilities as well as paint-line costs associated with the preparation, handling, spraying and baking or drying operations. In addition, it eliminates the costs of meeting stringent air-quality standards and paint-chemicals disposal requirements. The excellent paint film properties combined with advanced forming and joining technologies allow prepainted steel sheet to be used for many applications that, heretofore, were not possible. The result: short manufacturing and assembly cycles; affordable and salable products; a cleaner environment through the advanced pollution controls on the coating lines; and a better bottom line.

For exceptional usefulness in many industries...
Prepainted steel sheet is replacing other materials because of its application versatility. For example, in the construction industry, its availability in an almost infinite variety of colors, profiles, and strengths, means it can satisfy the most creative and discerning of architects and designers. As the following pages show, it can beautify structures for all kinds of purposes: schools, churches, town halls, malls, libraries, medical centers, recreation centers, gymnasiums, laboratories, garages, farm buildings, warehouses, factories, office buildings, as well as homes and apartment buildings. Prepainted steel sheet is equally versatile in other industries, appearing in homes, offices and commercial establishments in such items as washers, dryers, refrigerators, desks, file cabinets, computers and related devices, shelving, street signs, acoustical ceiling tiles, awnings, drapery rods and tracks -- the list is virtually endless.

Prepainted steel sheet has a number of practical advantages. In roofing, for example, it surpasses other materials in many ways, including improved resistance to drying out, cracking, splitting or warping. It offers the architect, designer or owner a way to obtain a roof that is durable as well as colorful and dramatic. In renovation projects, its low weight permits installation over old roofing, eliminating the time and expense of roofing removal and the need to truck the discard to landfills.

U.S. Steel offers a full range of prepainted steel sheet materials

USS Prepainted Steel Sheet is available in just about any combination of color, coating type and thickness, and metal thickness to meet any specific strength, design and decorative need.

(This photo shows roll application of paint to steel sheet in a continuous coil-coating paint line. In this modern process, computer control ensures paint films of uniformly high quality -- corrosion resistant and so tough, flexible and adherent that they withstand forming of the sheet into many shapes, some of which are shown on the following pages.)

Prepainted Steel Sheet offers these important advantages:

- Light weight due to high strength-to-weight ratio of steel
- Light weight means easier handling, lower shipping costs, easier installation
- Excellent dent resistance -- steel sheet withstands impacts from wind-borne objects
- Design flexibility -- multiplicity of grades and strength levels permits designing to specific needs
- Exciting colors -- rich tones in almost infinite variety
- High quality -- in recent years steel quality and paint technology have both improved greatly, the synergistic effect results in a high-performance material
- Recoatability -- prepainted steel sheet can be repainted to coordinate with changes in decor
- Readily available -- productivity gains combined with new facilities in recent years have made prepainted steel sheet expeditiously available in every geographical market.

Prepainted Steel Sheet protects your investment... and the environment

- Rigorous production control yields a highly uniform, high-quality, protective and decorative coating for long service life at low cost
- Color consistency -- for dependable visual uniformity
- Multiplicity of coating types and colors -- the paint performance can be engineered to exacting architectural needs and situations
- Prepainted steel roofing can provide a net cost saving over the product's service life
- Factory pollution control that is not economically feasible with post painting
- Cost effective -- highly durable, easy to fabricate and apply, prepainted steel sheet contributes good economic value and high quality for manufacturing many, many products today.

- - - - End U.S. Steel Siding Example Web Page - - - -

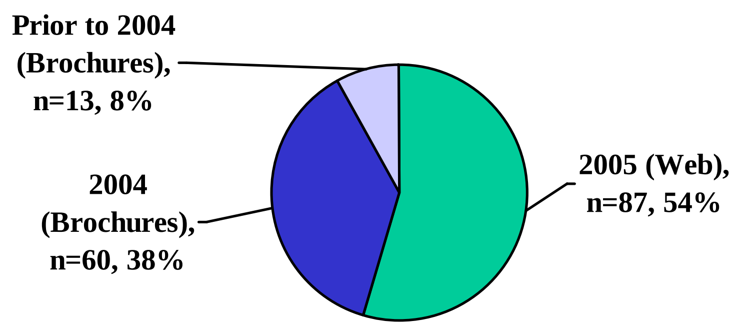


Figure 12 - Brochure/Web Publication Date Statistics

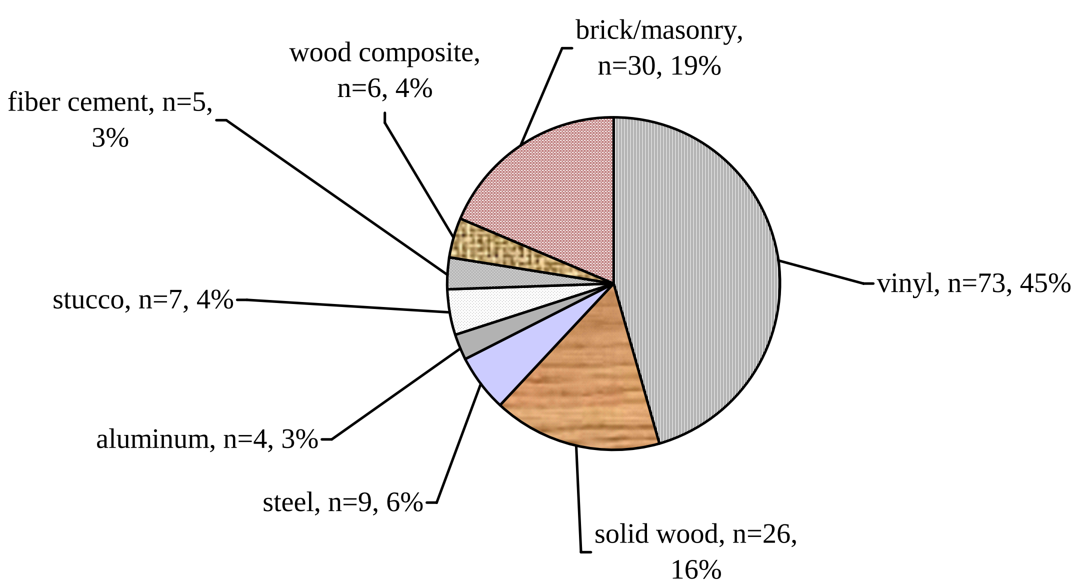


Figure 13 - Brochure/Web Percentages by Siding Material

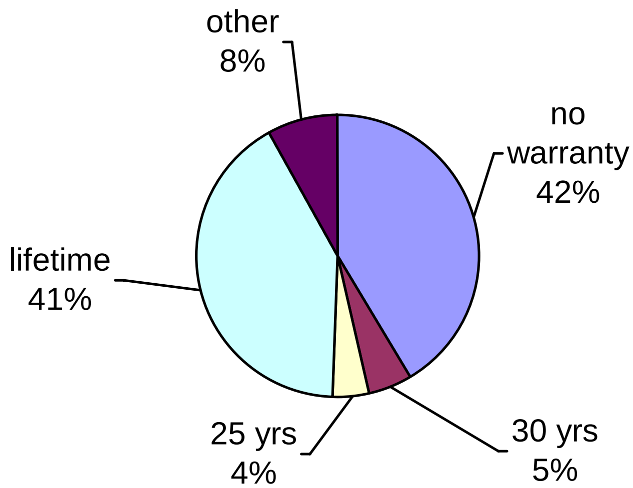


Figure 14 - Brochure/Web Product Warranty (years)

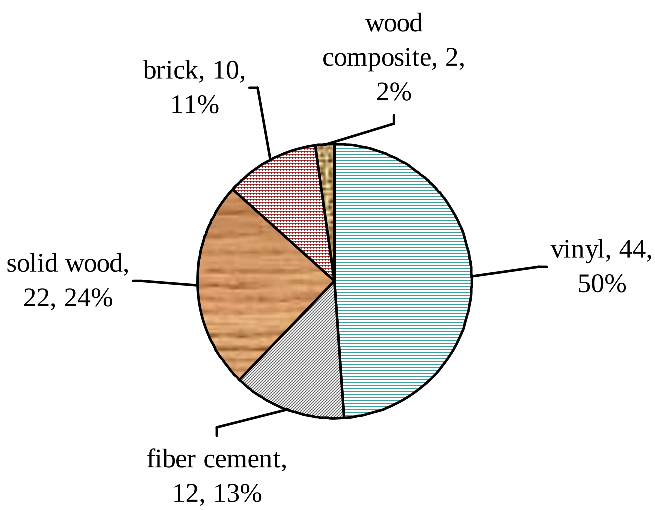


Figure 15 – Magazine Ads, Percentages by Siding Material

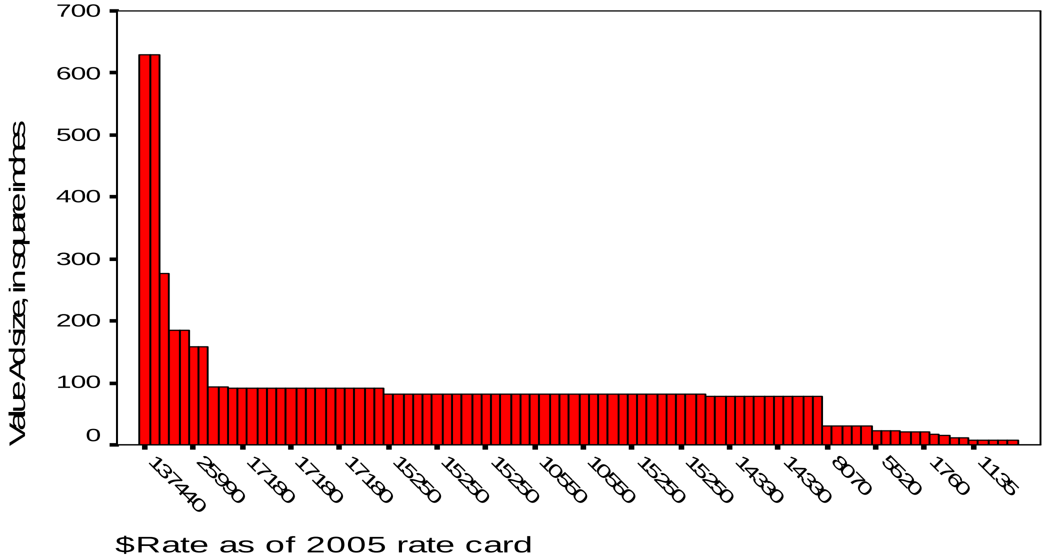


Figure 16 - Magazine ad sizes and rates

Durable Wood Composites for Naval Low-Rise Buildings

Evaluation of Interactions Between Coupling Agent, Wood Fiber and Polymer Matrix via Solid State NMR

Siding and Trim Components

Task S3) Evaluation of interactions between coupling agent, wood fiber and polymer matrix with solid state NMR

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Abstract

The use of wood plastic composites in exterior applications has increased greatly over the years, but the interaction between the components is not well understood. The major components of wood plastic composites (WPCs) are wood polymers, thermoplastics, coupling agents, and lubricants. Maleic anhydride polypropylene (MAPP) is a commonly used coupling agent in polypropylene based WPCs, while ethylene bisstearamide (EBS), the ester based OP100 and zinc stearate (ZnSt) are widely used lubricants. It has been noted in practice that the use of MAPP significantly increases the mechanical properties in PP based WPCs. However, that is with MAPP alone; the use of the lubricant ZnSt with MAPP decreases the improvement that is seen in the mechanical properties drastically. As for EBS and OP100, no change in mechanical properties is seen. The chemical interactions between MAPP, wood polymers, as well as lubricants, were studied with solid state ^{13}C CP MAS NMR, to determine the mechanism behind the coupling of MAPP with wood and how this (these) interaction(s) may be hindered by ZnSt. Esterification between MAPP and cellulose, lignin, and maple was uncovered while no interaction was seen between OP100 and EBS. ZnSt on the other hand has been found to hydrolyze MAPP and significantly disrupt the ability for MAPP to couple with wood.

Introduction

In recent years the interest in wood plastic composites has increased significantly. Due to the poor polar-nonpolar interactions between the hydrophilic wood and the hydrophobic polyolefin there is inadequate adhesion within the matrix. Considerable research has been performed to improve interfacial adhesion; one method of this includes adding a coupling agent into the composite. Maleic anhydride polypropylene (MAPP) is a widely used coupling agent within polypropylene based composites. The addition of MAPP shows a marked increase in the modulus of rigidity, MOR, and modulus of elasticity, MOE, of polypropylene, PP, based composites, indicating some form of interaction between the matrix and the MAPP.

MAPP has 2 forms, a closed ring anhydride and an open ring di-carboxylic acid form. Heinen et al determined the most probable structure of MAPP using smaller model compounds studied in solution with ^{13}C NMR (Heinen, 1999). This structure contains the closed ring anhydride form of MA grafted on the PP backbone. The MA functional group is capable of bonding with the wood and thereby bringing the wood and plastic matrices into contact and allowing for favorable interactions and entanglements between the components (Bratawinjaja, 1989). The proposed mechanisms for improvement in interfacial adhesion by MAPP include chemical bonding, wettability, intermolecular entanglement, and interfacial morphology.

Current research in the chemical interactions between MAPP and cellulose suggests esterification as the main interaction with a possibility of hydrogen bonding as well. Sanadi et al proposed that MA groups migrate towards the fiber surface (Figure 1) due to the polar/non-polar interactions, thus increasing the probability of bonding between the MA and the hydroxyl groups on the wood fibers or cellulose (Sanadi, 1992).

Using IR spectroscopy, several researchers have confirmed the existence of ester bonds between cellulose fibers and MAPP when the polymer blend has been prepared by solution casting (Felix, 1991; Joly, 1996). Kazayawoko et al have shown that while ester links are formed between cellulose and MAPP, there is no evidence of esterification between thermomechanical pulp and MAPP (Kazayawoko, 1997; Kazayawoko, 1999). The TMP and the

cellulose were reacted with MAPP in a solution of xylene and reacted for 2 hours between 130-140˚C. Felix et al immersed cellulose fibers in a solution of 5 wt % MAPP on the fibers and toluene at 100˚C for 5 minutes and then Sohxlet extracted for 48hrs to remove any non-covalently bonded components from the fibers (Felix, 1991). The fibers were then dried to a constant weight. FTIR of the cellulose/MAPP fibers showed MAPP was covalently bonded to the cellulose fibers via esterification. Matías et al used the same procedure to treat cellulosic materials with MAPP as Felix et al (Matías, 2000; Felix, 1991). The MAPP treated cellulose was determined via FTIR to have new ester bonds forming after treatment, as seen by the absorption band at 1730 cm^{-1}.

The interactions between MAPP and cellulose after melt mixing have also been studied (Qui, 2004; Qui, 2004). This sample preparation is more relevant to extrusion processes. Both melt mixing and ball mixing were performed and it was determined that the mechanochemical formation of reactive OH groups on the cellulose was the primary factor in the esterification between MAPP and cellulose. The FTIR data showed the characteristic ester peak at 1730 cm^{-1}. No difference in esterification was seen when different MAPP structures were used. It was also determined that ball-milling produced more esterification in the mix than melt-mixing due to the mechanochemical activation, leading to higher interfacial adhesion. When even small amounts of MAPP are used enhanced interfacial adhesion, MOR and MOE, is achieved, even though the FTIR spectra does not show the presence of ester bonds. This could be due to the low number of ester bonds due to low amounts of MAPP. The increased interfacial adhesion is still attributed to an esterification reaction between MAPP and cellulose (Qui, 2005), although other mechanisms may contribute to the enhanced interfacial adhesion. As a conclusion, while there is strong evidence for esterification between MAPP and cellulose, the mechanism between MAPP and wood is still not clear.

Wood plastic composites contain not only wood and plastic but frequently a coupling agent and a lubricant as well. Three major lubricants used are EBS, OP100 and Zinc Stearate (ZnSt). Interestingly, when EBS and OP100 lubricants are used in conjunction with MAPP, the performance enhancement usually imparted by MAPP is preserved (Wolcott, 2000). On the other hand, when ZnSt lubricant is used in conjunction with MAPP, the MAPP performance enhancement is completely annihilated. This suggests that ZnSt interferes with the coupling mechanism of MAPP (Wolcott, 2000). To date, only one study has been conducted to try and understand the mechanisms of interference of lubricants on MAPP adhesion enhancement mechanism. Namely, Harper et al determined that there is little interaction between the MAPP and EBS or OP100, while FTIR data shows ZnSt hydrolyzes MAPP negating the ability for MAPP to form a chemical link with the OH groups of wood, and decreasing the nucleating ability (Harper, 2006). Also the ability to form hydrogen bonds between wood and MA may not be as favored as the hydrogen bonds between MA and other hydrolyzed copolymers, such as ZnSt. This leads to the poor interaction and mechanical properties seen in composites when ZnSt is used. FTIR spectra of MAPP/ZnSt-EBS reveals a bond between the ZnSt and the MAPP, leading to the inhibition of bonding between wood fibers and MAPP (Harper, 2004). The ester based OP100 was also found to have increased fiber nucleating ability over the ZnSt-EBS blend.

Currently the chemical interactions between MAPP, wood, wood polymers, and lubricants is still not clear. Solid state NMR will be employed in an effort to determine the specific chemical interactions occurring between the MAPP and wood, wood polymers, and

lubricants. The determination of the interactions between MAPP and wood leading to enhanced performance can aid in designing better coupling agents for WPCs.

Experimental

Materials

Solid State ^{13}C CP NMR only detects the ^{13}C form of carbon which is of 1% natural abundance. With a small amount of MA grafted onto the PP backbone the detection of the MA would be very low. To increase the visibility of the MA functional group 100% ^{13}C enriched MAPP at the C1 and C4 carbons were used (Honeywell). The structures including the labeled carbons can be seen in figure 2. The C1 and C4 carbons were chosen because they are the functional groups that are believed to be involved in the coupling mechanisms. ZnSt, EBS and OP100 were purchased commercially, as was the cellulose, lignin, and maple.

Sample Preparation

The ^{13}C labeled MAPP, cellulose, lignin, maple, EBS, OP100 and ZnSt, were dried under vacuum to a constant weight and stored under vacuum, as were the resulting heated components and the blends. To determine MAPP/wood polymer interaction three blends were made at a ratio of 1:1, cellulose/MAPP, lignin/MAPP, and maple/MAPP. These blends were processed in an injection molder at 180˚C for 2 minutes. To determine the lubricant/MAPP interactions 3 additional blends were produced similarly, again at a ratio of 1:1, EBS/MAPP, OP100/MAPP, and ZnSt/MAPP, all processed under the same conditions as the wood polymer/MAPP blends. To further understand the interference of ZnSt lubricant on MAPP coupling mechanism with wood, 3 ternary blends of ZnSt/MAPP and cellulose, lignin or maple were processed under the same conditions at a 1:1:1 ratio. Samples of the components were heated in an oven at 180˚C for 2 minutes, for consistent comparison with the blends; these components will be considered neat components.

NMR

NMR spectroscopy gives detailed information of the types of functional groups present through the chemical shifts seen in the resulting spectrum. Each carbon has a distinctive chemical shift defined by its unique electronic environment. If esterification occurs, a change in chemical shift may be seen. Chemical shift predictions were used as a comparison in determination of new bonds. Another possible sign of new bonds or a change in the ratio of species present is a change in the peak shape or intensity. A change in spin lattice relaxation time, $T_{1\rho}$, can also cause a change in peak intensity and may indicate a change in the molecular motion of the molecule. Similar $T_{1\rho}$s between carbons in a material may indicate the same molecular motion; or homogeneity on a nanoscale level, which is called spin diffusion. To determine whether a change in intensity is due to a new species or a change in relaxation time, the $T_{1\rho}$ for each peak were measured using a variable contact time experiment. From these experiments the intensity of each peak was plotted against the contact time. The magnetization equation below was then fit to the curve and the $T_{1\rho}$ for each peak was obtained.

$$I(t) = I * ({}^{H}T_{1\rho} / ({}^{H}T_{1\rho} - T_{CH}))(\exp^{-t/T_{1\rho}} - \exp^{-t/T_{CH}})$$

The $T_{1\rho}$ data for each peak in the MAPP, wood, wood polymers, and lubricants is then compared to the $T_{1\rho}$ for the respective peak in the blends. If a change is seen in the $T_{1\rho}$ then the change in peak intensity may be from a combination of changes in $T_{1\rho}$, the ratio of species, or new species.

All NMR experiments were performed on a Bruker Avance 400. A 3.50µs proton 90 degree pulse was used with different contact times for the 13C and 1H channels and a proton decoupling field strength of 70kHz. Three replicates were analyzed by NMR and the chemical shifts were compared via t-test with an alpha value of 0.05. The neat components and the blends were analyzed at the optimum contact time of 1ms. The data was analyzed to determine if changes in the chemical shifts were present. Once changes were determined all neat components as well as the blends were subjected to variable contact time experiments. CP experiments with variable contact times (18 contact times, 0.025ms to 6ms) were run under the same parameters as the 1ms contact time experiments. The data was then plotted and curve fit using OriginPro7, and t-tests were used to determine significant changes ($p \leq 0.05$). Tukey tests were also used to determine similarity between relaxation times to group the peaks, indicated by the letters A, B, C... after the reported relaxation time.

Results

MAPP

The NMR spectrum of MAPP shows two distinct peaks at 180.1ppm and 173.5ppm in the carbonyl region that arise from the 13C enriched C_1 and C_4 carbons of the maleic moietie . (Figure 2). In addition, a shoulder at 165.6ppm appears. The two distinct peaks at 173.5ppm and 180.1ppm were believed to arise from the combined $C_1$and C_4 carbons of the closed and open ring maleic moieties, respectively. To confirm the assignment of each chemical shift to either the open ring C_1 and C_4 carbons or the closed ring C_1 and C_4 carbons, solution NMR spectra of maleic anhydride under various pH environments were acquired. Namely, maleic anhydride was dissolved in D_2O and adicified with HCl and a second solution was turned basic with NaOH. The basic solution was expected to have the open ring form of the MA while the anhydride form would be present in the acidic solution. It was determined the open ring form was present at 175.6ppm while the anhydride form appeared at 169.2ppm. From this it was confirmed that the higher chemical shift at 180.1ppm is the open ring while the lower shift at 173.5ppm was the anhydride form. The difference between the shifts in the solid and liquid state is likely due to the presence of the polypropylene backbone and the difference in state.

Chemical predictions using ChemDraw Ultra were made to determine the nature of the peak at 165.6 ppm. This peak was found to be the result of a MA grafted to the end of a PP chain by a double in the anhydride form. Outside the carbonyl region, the main chain carbons are observed at 44.4, 26.4 and 21.9ppm. The peak at 21.9ppm corresponds to the methyl group on PP, while the peak at 26.4ppm is the tertiary carbon and the final peak at 44.4ppm is the secondary carbon, joining tertiary carbons, (Figure 2). Once the chemistry of MAPP was understood, its phase morphology could be evaluated by $T_{1\rho}$.

The variable contact time experiments produced interesting results in regards to the $T_{1\rho}$ data. Table 1 contains the chemical shifts for the MAPP as well as the relaxation data. The two peaks corresponding to the MA groups have similar $T_{1\rho}$s, while the PP carbon peaks all have similar relaxation times. From this it can be concluded that the MA carbon groups have distinct molecular motion or are phase separated from the main chain PP. This type of behavior reflects

a structure in which the main chain PP entangles and crystallizes, excluding the MA groups from the PP structure.

MAPP/Wood blends

To determine the nature of interactions between wood and MAPP, binary blends of MAPP with cellulose, lignin and maple were evaluated. Any interaction between the cellulose and lignin with MAPP will likely be seen in the maple/MAPP blend.

Cellulose/MAPP

The cellulose/MAPP blend was evaluated with ^{13}C CP NMR and the resulting spectrum was first inspected for new peaks and changes in current peaks (Figure 3). All chemical shift data is summarized in Table 1. A new peak can be seen at 32.6ppm. This peak indicates a new species that was not present in either of the two neat components before blending. Based on the position of this peak and the intensity it appears to be a methane (CH_2) carbon. A methane carbon at 32.6ppm could occur as a result of MAPP chain scission. It is possible that is the presence of an acidic molecule such as cellulose some chain scission occurs within MAPP leaving a MA grouped double bonded to the end of a PP chain. Heinen et al also noted chain scission leading to a peak at 34.3ppm in his work with model compounds (Heinen, 1996).

The next change noted is the difference in intensity of the MA peaks, at 180.1ppm and 173.5ppm. The 173.5ppm peak is much more pronounced in the blend, and both peaks are also much broader. This intensity change is possibly due to a change in the number of species underlying these chemical shifts, namely open versus closed ring C1 and C4 carbons, or to a change in their relaxation time. However, the relaxation times of these resonances in the neat MAPP and in cellulose/MAPP blend are the same (Table 1) therefore the latter hypothesis can be eliminated. Intensity changes arise from changes in species concentration. It could also be due to the presence of new structures and thus chemical shifts that are overlapping in that area. In particular the possibility of the C_1 and C_4 being involved in an esterification reaction with the cellulose was examined via chemical shift predictions. The predicted chemical shift for an ester from the MAPP/Cellulose bond is 174.5ppm with the remaining carboxyl group appearing at 177.0ppm (Figure 3). Therefore if esterification between cellulose and MAPP were to occur, one would expect to see an increase in intensity around 174.5-177.0ppm along with a peak broadening. This is exactly what can be seen in figure 3 supporting the conclusion that esterification has occurred. This is consistent with the possibility of esterification between the MA of the MAPP and the cellulose hydroxyl groups. A change is not seen in the cellulose peaks. This is not unexpected as there are much larger amounts of cellulose hydroxyl groups in the blend than there are MA groups.

Table 1. ^{13}C NMR data for Cellulose/MAPP blend

Chemical Shifts for Cellulose/MAPP blend					**Relaxation Time ($T_{1\rho}$, ms)**			
Peaks (ppm)	**MAPP**	**Cellulose**	**Cellulose/ MAPP**	**ppm change**	**MAPP**	**Cellulose**	**Cellulose/ MAPP**	**$T_{1\rho}$ change**
180	180.1±0.3		180.0±0.4		3.6±0.3, A		3.6±0.4, BC	
173	173.5±0.1		173.4±0.3		3.9±0.1, A		3.9±0.3, AB	
105		105.6±0.1	105.3±0.4			5.5±0.4, A	4.3±0.8, AB	
89		89.0±0.2	89.3±0.5			6.4±0.9, A		
83		83.4±0.9	82.7±0.6			5.3±0.4, A		
74		74.9±0.1	74.8±0.1			5.0±0.5, A	4.0±0.7, AB	1.0ms
65		65.0±0.0	65.1±0.3			5.6±0.7, A		
44	44.4±0.3		44.1±0.3		5.3±0.3, B		4.6±0.2, AB	0.7ms
32.6			32.6±0.2	New Peak			2.6±0.3, C	New Peak
26	26.4±0.3		26.2±0.2		5.4±0.3, B		5.1±0.2, A	
21	21.9±0.3		21.8±0.2		4.9±0.1, B		4.3±0.2, AB	0.6ms

Second we examine phase morphology and molecular motions by examining $T_{1\rho}$ data. From the $T_{1\rho}$ data one can conclude that cellulose alone is completely homogeneous in its relaxation while MAPP has one relaxation domain of just MA groups and a second domain of only the PP main chain groups. Upon blending cellulose with MAPP all the carbons but the new carbon at 32.6ppm have the same $T_{1\rho}$. This indicates that these carbons either have similar motional characteristics or that spin diffusion occurs between these carbons averaging out motional characteristics. Therefore, the MAPP carbons are intimately meshed with the cellulose carbons. It is also noted that the segregation between functional carbons and main chain carbons of the MAPP is no longer occurring within the blend. To conclude, cellulose and MAPP are intimately mixed and ester bonds form between cellulose hydroxyl groups and the maleic anhydride groups of MAPP.

Lignin/MAPP

The lignin/MAPP blend was analyzed via the same methods as the MAPP/cellulose blend. Table 2 shows the results for chemical shifts and $T_{1\rho}$ of lignin, MAPP and its blend. The same behavior seen in the MAPP/cellulose blend can be seen in the MAPP/lignin blend (figure 4). A new peak is seen again at 32.7ppm and the 173.5ppm peak in the blend than in the neat MAPP. This new peak is again likely due to chain scission of MAPP either to the acidic nature of lignin, or to the presence of free radicals. Using ChemDraw Ultra to predict chemical shifts, it was determined that an esterification reaction between MAPP and lignin would lead to chemical shifts at 169.0ppm, 172.0ppm and 179.5ppm. These shifts would overlap the already present MA shifts of MAPP, leading to a change in intensity of these peaks. This change in the intensities is either an indication of H-bonding, esterification or a change in relaxation time. To determine this, the relaxation times of both the MAPP and lignin were compared with that of the blend.

Table 2. ^{13}C NMR data for Lignin/MAPP blend

Chemical Shifts for Lignin/MAPP blend					Relaxation Time ($T_{1\rho}$, ms)			
Peaks (ppm)	**MAPP**	**Lignin**	**Lignin/ MAPP**	**ppm change**	**MAPP**	**Lignin**	**Lignin/ MAPP**	**$T_{1\rho}$ change**
180	180.1±0.3		179.6±0.4		3.6±0.3 A		4.1±1.0 AC	
173	173.5±0.1		173.9±0.4		3.9±0.1 A		5.0±0.5 BA	1.1ms
147		147.5±0.2	147.2±0.6			12.8±0.9, A		
123		123.4±1.1	123.8±0.7			13.2±1.5, A		
115		115.2±0.3	115.9±1.0			8.8±0.4, B		
73		73.6±0.7				7.3±0.6, B		
55		55.6±0.2	55.4±0.2			7.9±0.2, B	6.4±0.2, A	1.5ms
44	44.4±0.3		44.3±0.2		5.3±0.3 B		5.1±0.3 BA	
32.7			32.7±0.2	New Peak			3.5±0.8, C	New Peak
26	26.4±0.3		26.3±0.3		5.4±0.3 B		5.5±0.2 BA	
21	21.9±0.3		21.8±0.3		4.9±0.1 B		4.8±0.3 BC	

The $T_{1\rho}$ of the peak at 173.5ppm shows an increase of 1.1 ms. The large change seen in the $T_{1\rho}$ of the peak at 173.5ppm shows that the change in intensity is due to not only esterification but in part to a change in relaxation time, This is further indication of a new species and clear evidence of esterification between MAPP and lignin.

Maple/MAPP

In the maple/MAPP blend, the same changes seen in both the cellulose and lignin blends are observed (Figure 5). The new peak at 32.6ppm is present (Table 3) and much larger in the maple/MAPP blend than has been seen before, indicating MAPP chain scission when processed with maple. The peak at 173.5ppm again has a much larger intensity and broader than in the neat MAPP alone. As for cellulose and lignin with MAPP, this change in intensity likely reflects esterification between wood polymers and MAPP.

Table 3. ^{13}C NMR data for Maple/MAPP blend

Chemical Shifts for Maple/MAPP blend					Relaxation Time ($T_{1\rho}$, ms)			
Peaks	**MAPP**	**Maple**	**Maple/ MAPP**	**ppm change**	**MAPP**	**Maple**	**Maple/ MAPP**	**$T_{1\rho}$ change**
180	180.1±0.3		179.8±0.2		3.6±0.3, A		3.1±0.3, A	
173	173.5±0.1		173.4±0.2		3.9±0.1, A		3.5±0.2, AB	0.4ms
105		105.4±0.1	105.1±0.4			7.1±0.3, A	4.3±0.3, BC	2.8ms
83		83.6±0.7	82.5±0.4			6.9±0.4, A		
73		73.3±1.2	74.7±0.4			6.9±0.3, A	4.1±0.5, BC	2.8ms
64		64.4±0.9	65.3±0.6			7.3±0.9, A		
55		55.6±0.6	56.4±0.3			11.1±1.2, B		
44	44.4±0.3		44.3±0.2		5.3±0.3, B		4.3±0.2, BC	1.0ms
32.6			32.6±0.2	New Peak			3.8±0.5, AB	New Peak
26	26.4±0.3		26.3±0.2		5.4±0.3, B		5.0±0.3, C	
21	21.9±0.3		21.8±0.3		4.9±0.1, B		4.3±0.3, BC	0.6ms
20		20.4±0.2						

Now, upon blending the $T_{1\rho}$ of some cellulose carbons (C1, C2, C3, C5) alone with the $T_{1\rho}$ of the peak at 173.5ppm have significant changes. Upon blending the motional characteristics of these carbons are therefore changing. In addition most carbons have the similar $T_{1\rho}$, therefore this indicates an esterification reaction is occurring between wood and MAPP.

Conclusions

The cellulose/MAPP, lignin/MAPP, and maple/MAPP blends all show evidence of esterification. In previous research esterification has been seen only between cellulose and MAPP, while the presence of esterification between lignin and wood with MAPP during melt processing was not seen previously.

MAPP/Lubricants

As the interactions between wood and MAPP have been studied, the same methods of study were conducted to determine the interactions between the three major lubricants and MAPP. These include an EBS/MAPP blend, OP100/MAPP blend, and ZnSt/MAPP blend. As no changes in mechanical properties are seen with the use of EBS and OP100 littler interaction is expected to be seen. On the other hand, the ZnSt/MAPP blend is expected to have some interactions as a significant loss in mechanical properties are seen in WPCs with MAPP and ZnSt.

EBS/MAPP

The spectrum of the EBS/MAPP blend shows an overlap of the EBS C=O peak with the MAPP anhydride peak at 173.5 ppm (Figure 6). The only statistically significant change in chemical shift was the main chain EBS peak seen at 33.9 shifting to 34.0 after blending, Table 4. This peak corresponds to the carbons directly next to the C=O carbons, and is likely due to a change in conformation and nothing more, therefore it is likely there are no chemical interactions present in the blend. To determine any changes in morphology the relaxation times were studied.

Table 4. ^{13}C NMR data for EBS/MAPP blend

Chemical Shifts for EBS/MAPP blend					Relaxation Time ($T_{1\rho}$, ms)			
Peaks ppm	MAPP	EBS	EBS/MAPP	ppm change	MAPP	EBS	EBS/MAPP	T1ρ change
180	180.1±0.3		180.0±0.5		3.6±0.3 A		3.7±0.4 A	
173	173.5±0.1	173.6±0.0	173.7±0.1		3.9±0.1 A	4.7±0.2 A	3.8±0.3 A	
44	44.4±0.3		44.4±0.0		5.3±0.3 B		5.1±0.2 B	
40		40.2±0.0	40.2±0.1			4.8±0.1 A	4.0±0.4 AC	0.8ms
33		33.9±0.0	34.0±0.0	0.1ppm		5.4±0.0 B	5.1±0.5 B	
27		27.0±0.0				4.9±0.2 A		
26	26.4±0.3		26.4±0.0		5.4±0.3 B		5.5±0.3 B	
24		24.6±0.0				5.4±0.1 A		
21	21.9±0.3		21.9±0.0		4.9±0.1 B		5.0±0.2 B	
14		14.3±0.0	14.3±0.1			6.5±0.3 C	5.0±0.3 BC	1.5ms

The first thing to be noted in regards to the relaxation time is that the center two CH_2 groups of EBS, 40.2ppm, show a 0.8ms decrease in $T_{1\rho}$, and the terminal methyl of the EBS

shows a 1.5 ms decrease as well. The MAPP shows no change in $T_{1\rho}$ for any of the peaks. Therefore the EBS motional characteristics are altered to some degree when crystallized with MAPP. Furthermore, there is a clear difference in the $T_{1\rho}$ of the carbonyl functional groups and the aliphatic groups, whether from MAPP or EBS. Namely, the carboxylic carbons have different motional characteristics than the aliphatic carbons showing segregation of polar and non polar carbons as previously observed in neat MAPP. To conclude, apart from a slight change in EBS conformation induced by the MAPP, no clear interaction between EBS and MAPP exist.

OP100/MAPP

Figure 7 shows the NMR of OP100/MAPP blend and compared to the neat components. Little interaction can be seen in the OP100/MAPP blend, Table 5. The only change in chemical shift was seen in the peak at 33.3 ppm, main chain carbon peak, this shifted to 33.2ppm; this peak is likely from the carbons directly next to the ester groups, similar to that seen in EBS. There may be a small change in the conformation of the main chain for OP100 but little other interaction between the MAPP and OP100. The change in peak shape for the peak at 173.5ppm in the blend is due to the overlap of OP100 ester group with the MAPP anhydride.

Table 5. ^{13}C NMR data for OP100/MAPP blend

Chemical Shifts for OP100/MAPP blend					Relaxation Time ($T_{1\rho}$, ms)			
Peaks	**MAPP**	**OP100**	**OP100/ MAPP**	**ppm change**	**MAPP**	**OP100**	**OP100/ MAPP**	**$T_{1\rho}$ change**
180	180.1±0.3		179.6±0.3		3.6±0.3 A		3.1±0.7 A	
173	173.5±0.1	172.8±0.0	173.0±0.2		3.9±0.1 A	4.9±0.5 A	3.6±0.4 AB	
44	44.4±0.3		44.4±0.1		5.3±0.3 B		4.6±0.3 CD	
42		42.3±0.1				2.7±0.2 B		
33		33.3±0.0	33.2±0.0	0.1ppm		3.9±0.1C	3.8±0.2 ABC	
26	26.4±0.3		26.4±0.0		5.4±0.3 B		5.0±0.1 D	
24		24.7±0.0				4.1±0.2C		
21	21.9±0.3		21.9±0.1		4.9±0.1 B		4.6±0.2 BCD	
14		14.6±0.0	14.6±0.0			9.1±0.5D	7.9±0.3 E	1.2ms

To confirm no change in the anhydride/ester peak the relaxation data was reviewed. The $T_{1\rho}$ data for this blend shows a change only in the methyl group of the OP100. The relaxation time for this peak actually decreases. Furthermore, the original phase separation seen in each component by itself is seen in the blend. There is likely little interaction if any between the OP100 and the MAPP. This was expected as there is no effect on the MOR and MOE when OP100 is added to a MAPP containing WPC.

ZnSt/MAPP

Many changes are apparent in the ZnSt/MAPP blend (Figure 8). First the stearate peak at 185.3ppm shifts to 184.9ppm, the peak at 180.1ppm shifts to 181.4ppm, and the peak at 173.5ppm to 174.4ppm. The main chain peaks also experienced some change as well, the ZnSt peak at 33.9 shifted to 34.1, and the ZnSt main chain peak at 28.1 shifted to 28.5 ppm, while the terminal methyl shifted to 14.7 from 14.4 ppm. These shifts all indicate a significant reaction is occurring in the blend. ZnSt may cause more of the open ring MAPP to form, or the ZnSt may complex with the MAPP, or the stearate alone may bond with the MAPP. Figure 8 shows the ZnSt and the stearate complexation reactions with MAPP, which would cause the changes seen

in chemical shift. The changes seen in the chemical shifts of the main chain also indicate that there is a possible change in conformation, crystallinity, or mobility which can all be brought on by the interaction between the MA and carboxylic groups on the ZnSt.

Table 6. ^{13}C NMR data for ZnSt/MAPP blend

Chemical Shifts for ZnSt/MAPP blend					**Relaxation Time ($T_{1\rho}$, ms)**			
Peaks	**MAPP**	**ZnSt**	**ZnSt/MAPP**	**ppm change**	**MAPP**	**ZnSt**	**ZnSt/MAPP**	**$T_{1\rho}$ change**
185		185.3±0.0	184.9±0.0	0.5ppm		5.9±0.6 A	4.9±0.2, A	1.0ms
180	180.1±0.3		181.4±0.3	1.3ppm	3.6±0.3, A		3.7±0.3, B	
173	173.5±0.1		174.4±0.3	0.9ppm	3.9±0.1, A		3.5±0.3, B	
44	44.4±0.3		44.4±0.0		5.3±0.3, B		5.3±0.3, A	
33		33.9±0.0	34.1±0.0	0.2ppm		6.0±0.1 A	5.0±0.3, A	1.0ms
28		28.1±0.0	28.5±0.0	0.4ppm		5.4±0.1 A		
26	26.4±0.3		26.3±0.0		5.4±0.3, B		5.5±0.5, AC	
24		24.7±0.4				6.7±0.1 B		
21	21.9±0.3		21.9±0.0		4.9±0.1, B		4.8±0.2, A	
14		14.4±0.0	14.7±0.0	0.3ppm		9.2±0.5C	6.4±0.5, C	2.8ms

The $T_{1\rho}$ data for this blend shows no change in mobility of the MAPP carbons, while changes are noted in the carboxylic groups, the main chain group at 33.9ppm, and the methyl group of the ZnSt, indicating the ZnSt is the most changed molecule in the blend. The carboxylic group of the ZnSt shows a relaxation time decrease of 1ms, as does the main chain peak at 33.9 ppm. The terminal methyl for the ZnSt also shows a decrease of nearly 3ms. Interestingly both the MAPP and the ZnSt show the same phase separation after blending that was seen in the neat components, even after the changes in T1ρ are taken into account. It is interesting to note that the even though the same phase separation is present both components show similar relaxation times for their main chain carbons. There is likely to be spin diffusion between the main chains while the MA groups and the carboxylic groups are both phase separated from the rest of the blend and each other.

Conclusions

As expected no significant interactions between EBS, OP100 and MAPP are noted. On the other hand, ZnSt blend showed significant changes in the chemistry indicating a large interaction between the MAPP and ZnSt. Clearly ZnSt chemically interacts with MAPP. This is consistent with the fact that EBS and OP100 do not inhibit MAPP while ZnSt seriously decreases the efficiency of MAPP.

Ternary Blends

The large interactions of ZnSt with the MAPP warranted the study of ternary blends of ZnSt/MAPP and cellulose, lignin, and maple. Namely, ZnSt/cellulose/MAPP, ZnSt/lignin/MAPP and ZnSt/maple/MAPP blends. Based on the results of the binary blends we will look only at the functional groups of MAPP and ZnSt.

ZnSt/Cellulose/MAPP

Figure 9 shows the spectrum of the cellulose based ternary blend. Initially one can see that there is a definite change in peak shape in the MA group region, and that the peak shapes

resembles that seen in the ZnSt/MAPP more so than that seen in the cellulose/MAPP blend. The changes in chemical shift are examined, Table 7. The functional groups for both MAPP and ZnSt show changes in chemical shift. The chemical shift changes seen are very similar to those seen with ZnSt/MAPP alone. Further, the relaxation data also shows that the changes in peak shape are not due to a change in relaxation time. This indicates that when both ZnSt and cellulose are present with MAPP, the interaction between ZnSt and MAPP dominates that between MAPP and cellulose. In other words, ZnSt wins over cellulose in interacting with MAPP.

Table 7. ^{13}C NMR data for ZnSt/Cellulose /MAPP blend

Chemical Shifts for ZnSt/Cellulose/MAPP blend						Relaxation Time ($T_{1\rho}$, ms)				
Peaks	**MAPP**	**ZnSt**	**Cellulose**	**Ternary blend**	**ppm change**	**MAPP**	**ZnSt**	**Cellulose**	**Ternary blend**	**$T_{1\rho}$ Change**
185		185.3±0.0		185.6±0.1	0.3		5.9±0.6		5.4±0.4	
180	180.1±0.3			182.3±0.3	1.2	3.6±0.3			4.0±0.3	
173	173.5±0.1			174.5±0.5	1.0	3.9±0.1			4.1±0.8	

ZnSt/Lignin/MAPP

In the ZnSt/Lignin/MAPP blend the 173ppm shows a significant increase in intensity (Figure 10), which again resembles the ZnSt/MAPP much more than the lignin/MAPP blend. Both the MA peaks show downfield shifts, while the ZnSt peak at 185ppm does not change, Table 8. These changes again indicate the interaction between ZnSt and MAPP is favored over any interaction between MAPP and lignin. The change in T1ρ of the peak at 180ppm is likely due to a change in crystallinity after blending. In this ternary blend it is evident that the ZnSt interacts with the MAPP and that there is little if no interaction between the ZnSt and lignin.

Table 8. ^{13}C NMR data for ZnSt/Lignin/MAPP blend

Chemical Shifts for ZnSt/Lignin/MAPP blend						Relaxation Time ($T_{1\rho}$, ms)				
Peaks	**MAPP**	**ZnSt**	**Lignin**	**Ternary blend**	**ppm change**	**MAPP**	**ZnSt**	**Lignin**	**Ternary blend**	**$T_{1\rho}$ change**
185		185.3±0.0		185.1±0.4			5.9±0.6		5.6±0.3	
180	180.1±0.3			182.1±0.3	2.1ppm	3.6±0.3			4.3±0.2	1.7ms
173	173.5±0.1			175.4±1.1	1.9ppm	3.9±0.1			3.9±0.8	

ZnSt/Maple/MAPP

The spectrum of the maple based ternary blend can be seen in Figure 11. Similar observations seen in the ZnSt/cellulose/MAPP blend and the ZnSt/lignin/MAPP blend can be made here. Namely, the ZnSt/maple/MAPP spectrum is very similar to that of the ZnSt/MAPP and different from that of the maple/MAPP blend. The changes in chemical shift are also more similar to that seen in the ZnSt/MAPP blend, Table 9. Again, this means that the ZnSt/MAPP interaction dominates the interaction of maple and MAPP. Both the MA functional groups and the ZnSt carboxyl group show similar $T_{1\rho}$ after blending allowing for spin diffusion to occur, and homogeneity between these functional groups. It appears that the MAPP has a much larger interaction with the ZnSt than the maple. Furthermore, these findings are consistent with the decreased mechanical properties found in WPCs containing both MAPP and ZnSt.

Table 9. ^{13}C NMR data for ZnSt/Maple/MAPP blend

Chemical Shifts for ZnSt/Maple/MAPP blend						Relaxation Time ($T_{1\rho}$, ms)				
Peaks	**MAPP**	**ZnSt**	**Maple**	**Ternary blend**	**ppm change**	**MAPP**	**ZnSt**	**Maple**	**Ternary blend**	**T1ρ change**
185		185.3±0.0		185.2±0.1			5.9±0.6		4.5±0.4	1.4ms
180	180.1±0.3			182.9±0.2	2.8ppm	3.6±0.3			3.7±0.1	
173	173.5±0.1			174.9±0.5	1.5ppm	3.9±0.1			3.9±0.5	

Conclusions

NMR evaluation of blends with cellulose, lignin, or maple and MAPP show that esterification occurred between the wood polymers and the MAPP during melt processing. Also, both lignin and cellulose are involved in the esterification between wood and MAPP. The esterification between wood and the MAPP allow for miscibility and homogeneity within these two component blends.

On the other hand, little interaction between MAPP and EBS or OP100 is observed. Upon blending, the ZnSt causes large differences in the chemical shifts of the MA functional groups as well as most of the ZnSt main chain carbons. These changes are due to the bonding likely occurring between MAPP and ZnSt during melt processing.

The ternary blends of the ZnSt/wood polymer/MAPP all show that the interaction of the ZnSt with the MAPP is preferred over interaction of the MAPP with the wood polymers. Overall it can be seen that ZnSt hinders the coupling between MAPP and wood. In order to have effective coupling between MAPP and wood, the lubricants used must not be able to interact with the maleic anhydride groups of the MAPP. This means that the metal based lubricants will most likely be less effective as the metal may disassociate from the rest of the molecule leaving open ended and reactive functional groups to interact and possibly hydrolyze the MAPP. An effective coupling agent will contain functional groups able to covalently bond with the hydroxyl groups of wood and in turn have a backbone compatible with the polymer matrix, such as PMPPIC.

Acknowledgements

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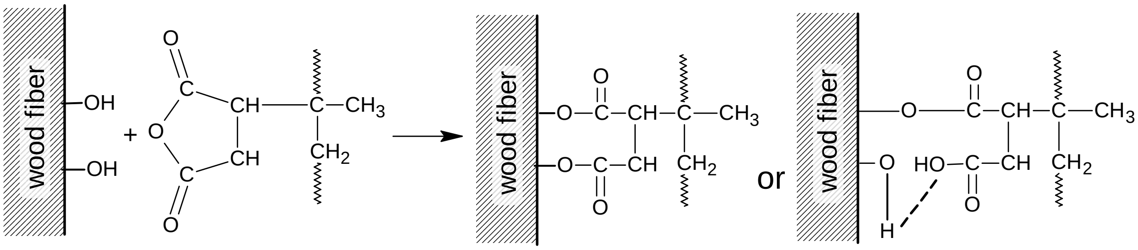

Figure 1. Reaction Schema of MAPP and wood fibers (Sanadi, 1992)

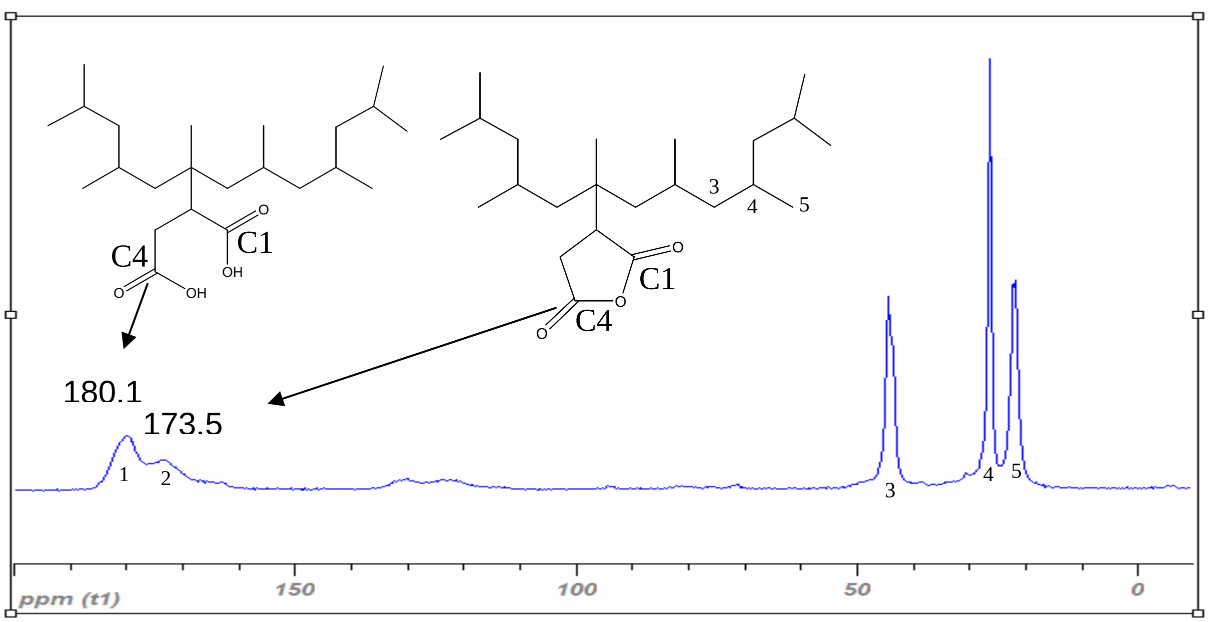

Figure 2: ^{13}C NMR of MAPP

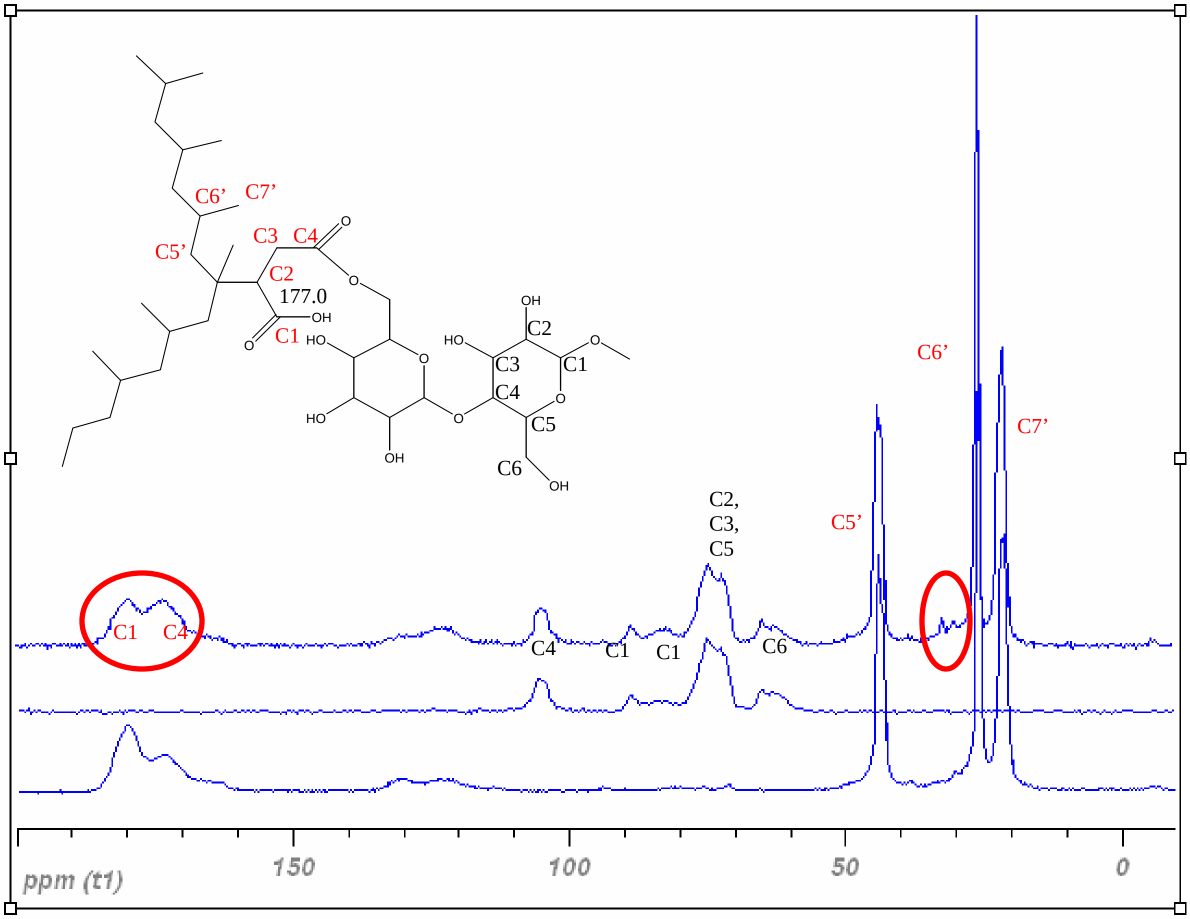

Figure 3. ^{13}C NMR of MAPP/Cellulose, proposed esterification of MAPP and Cellulose

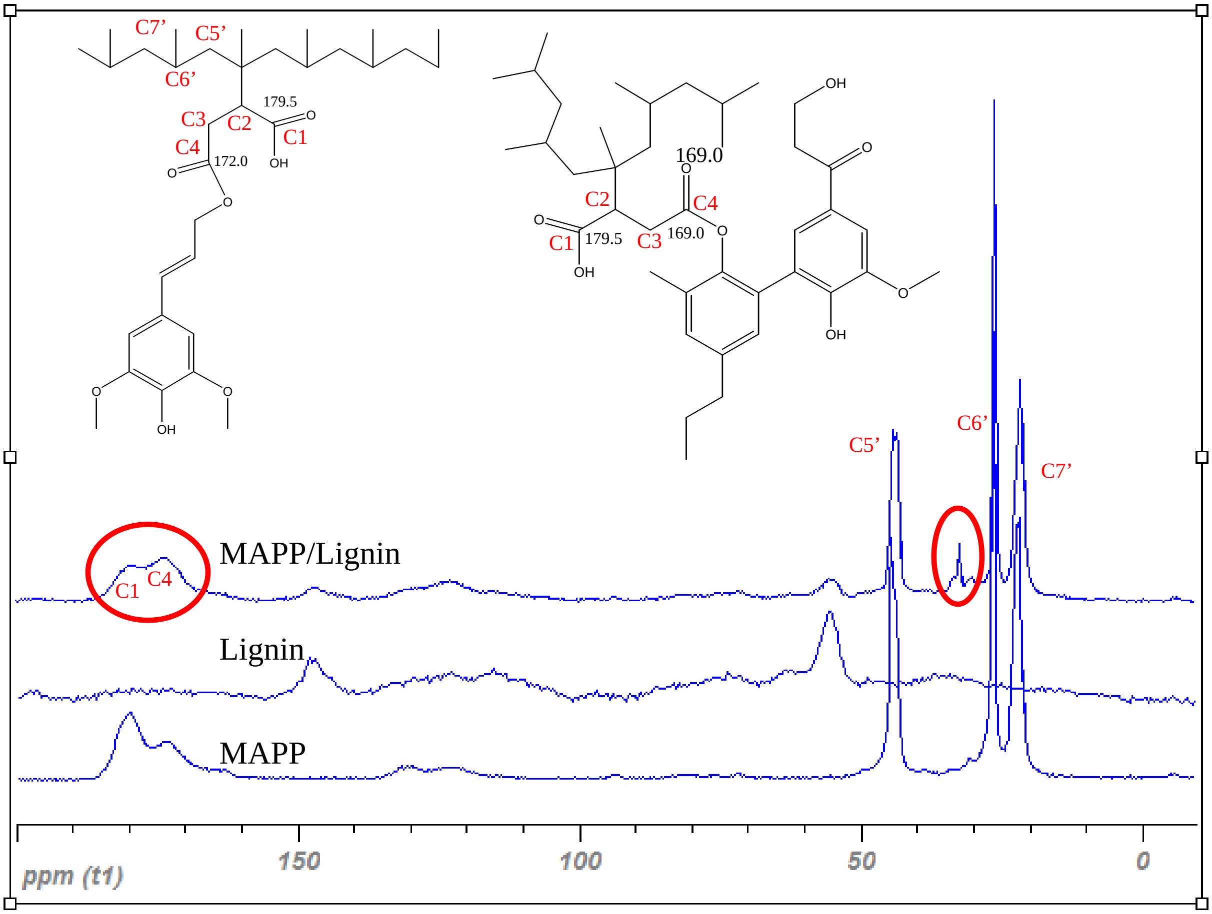

Figure 4. ^{13}C NMR of MAPP/Lignin blend

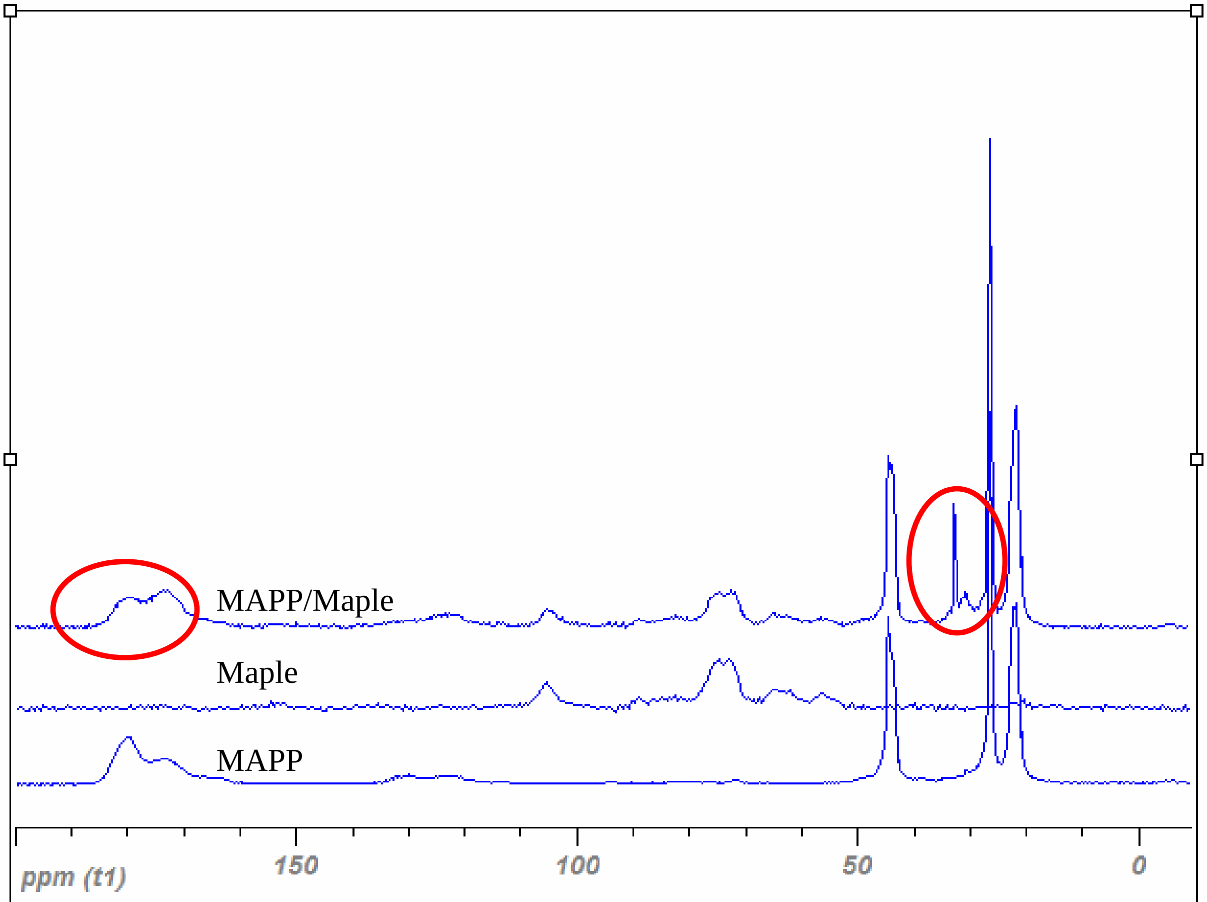

Figure 5: ^{13}C NMR of MAPP/Maple blend

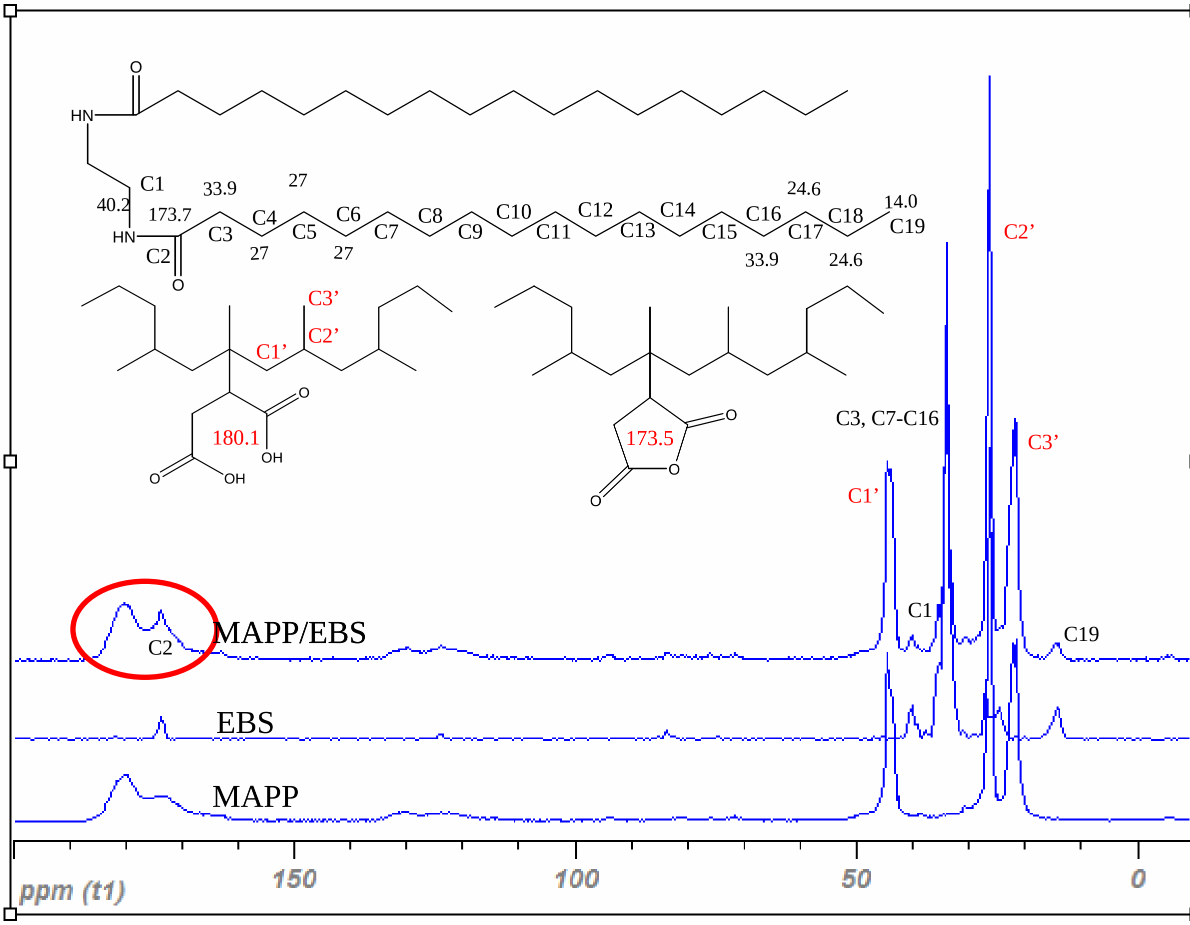

Figure 6: ^{13}C NMR of EBS/MAPP

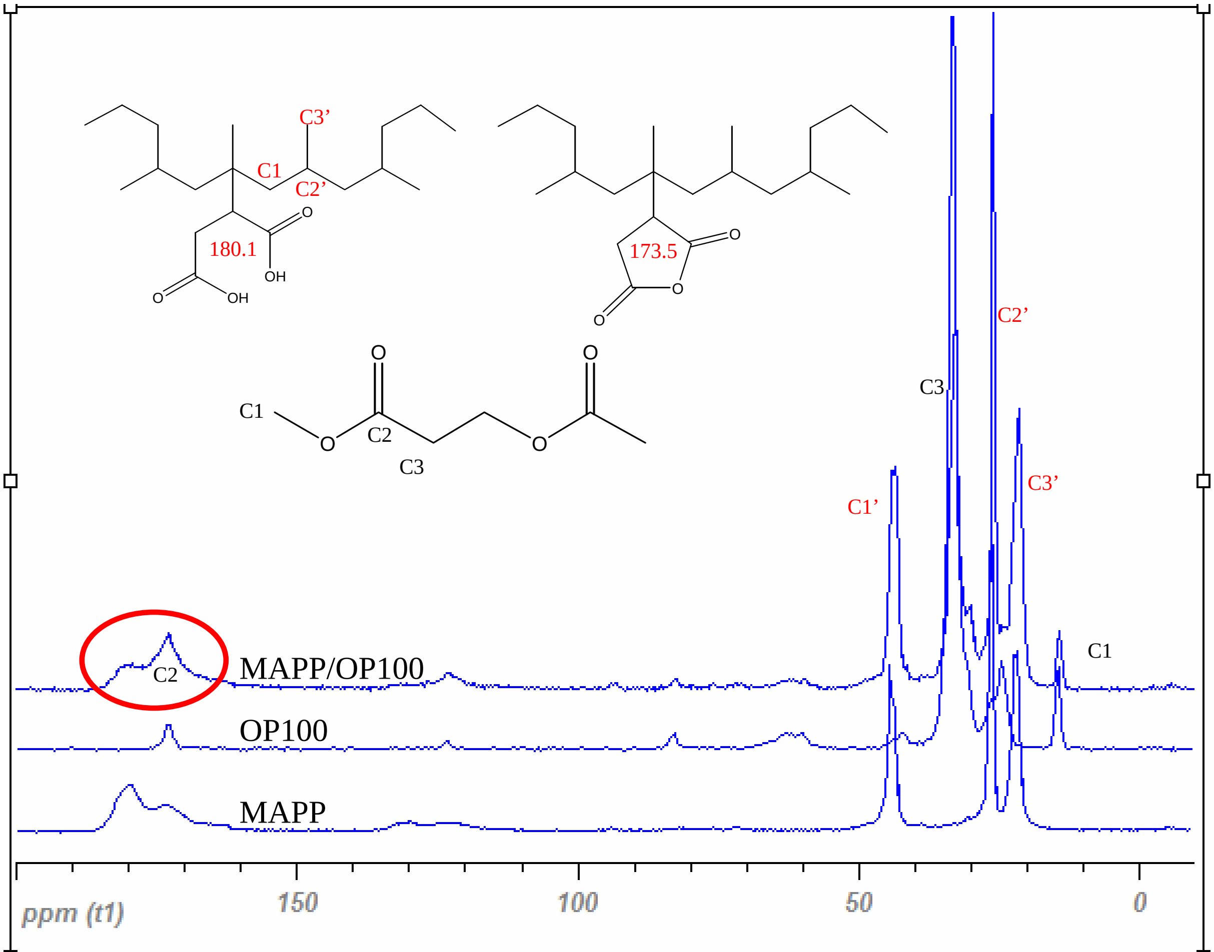

Figure 7: ^{13}C NMR of OP100/MAPP blend

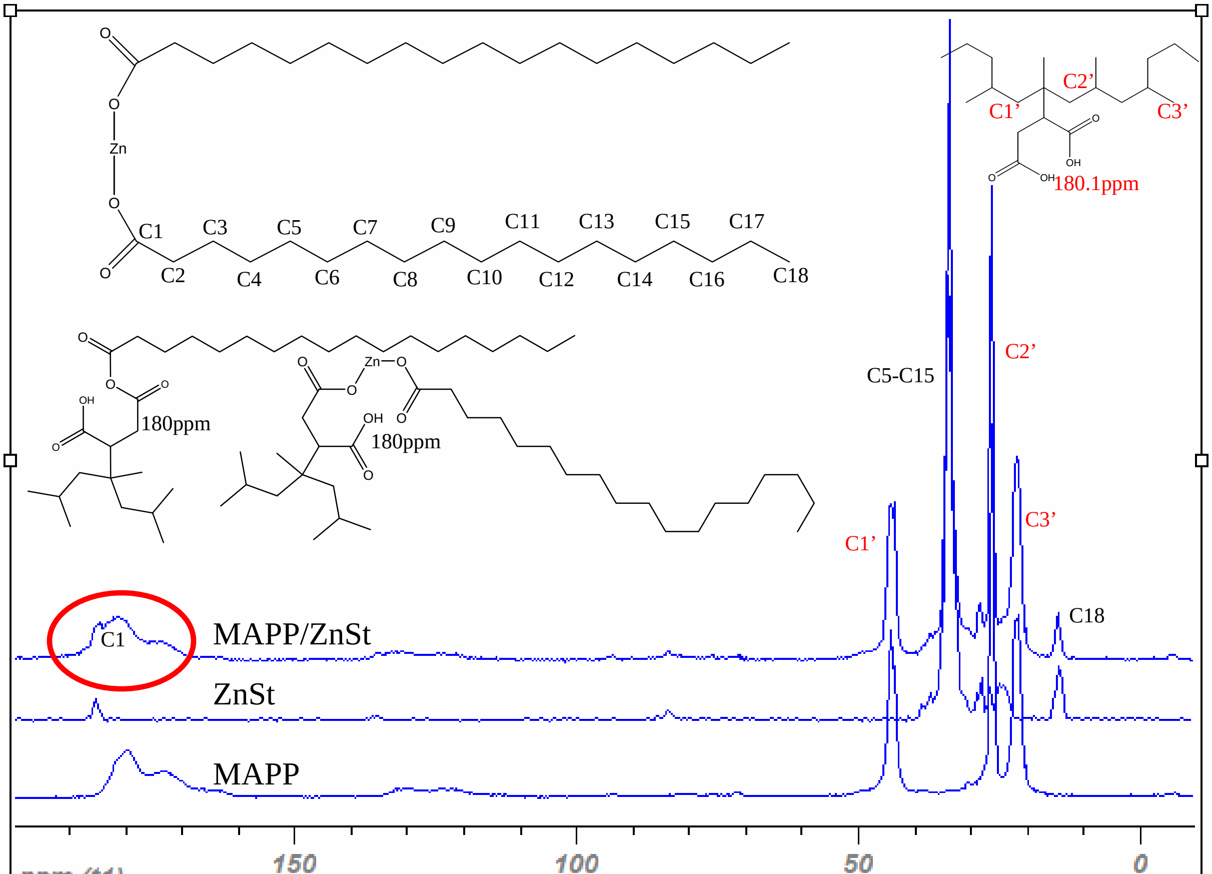

Figure 8: ^{13}C NMR ZnSt/MAPP blend

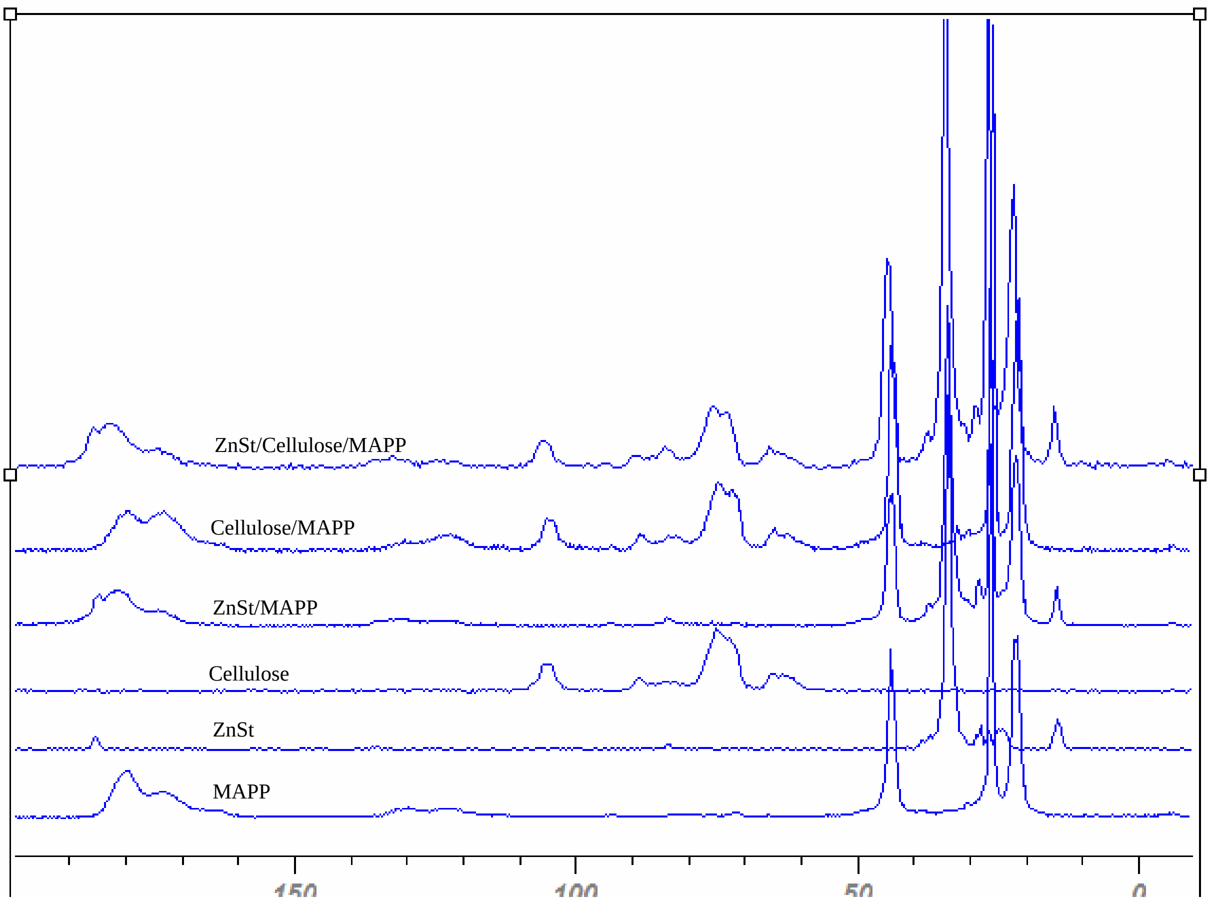

Figure 9: ^{13}C NMR of ZnSt/Cellulose/MAPP blend

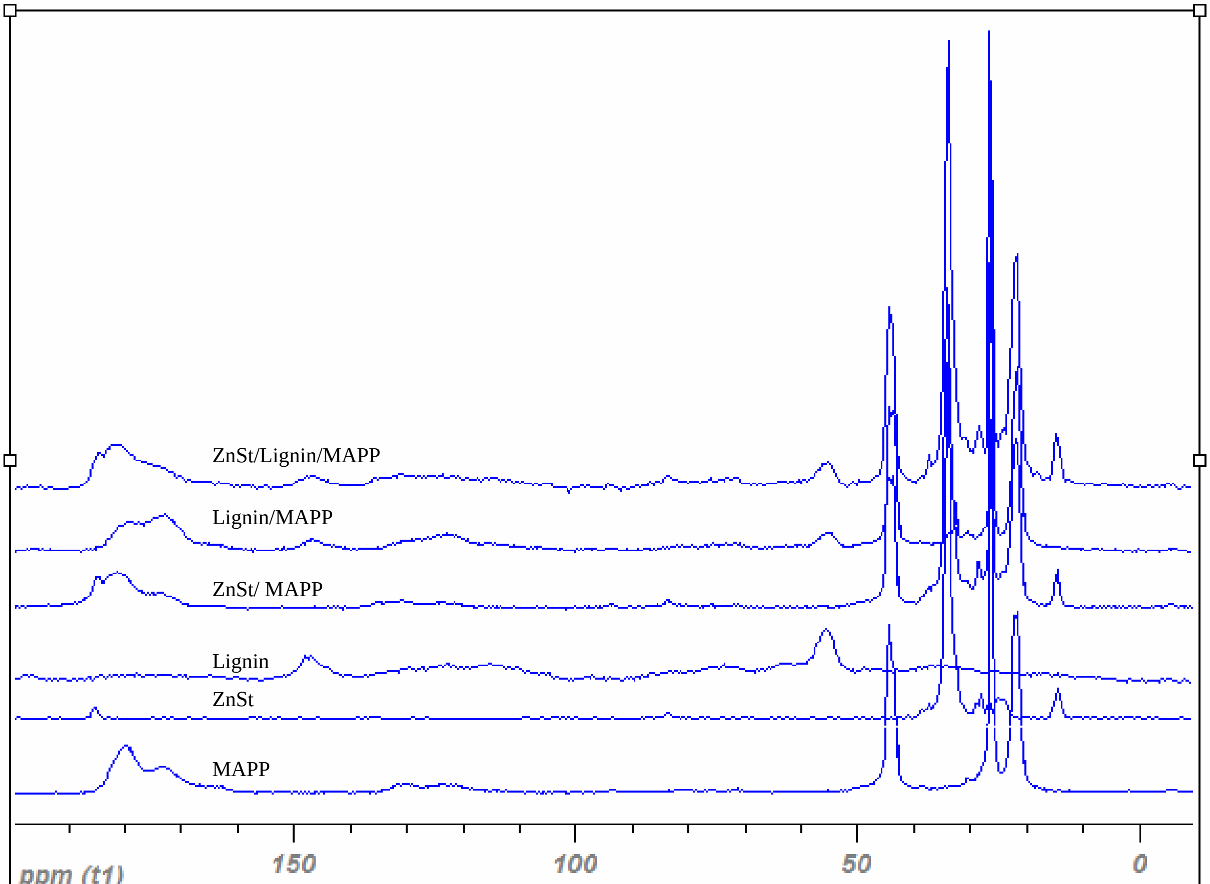

Figure 10: ^{13}C NMR of ZnSt/Lignin/MAPP blend

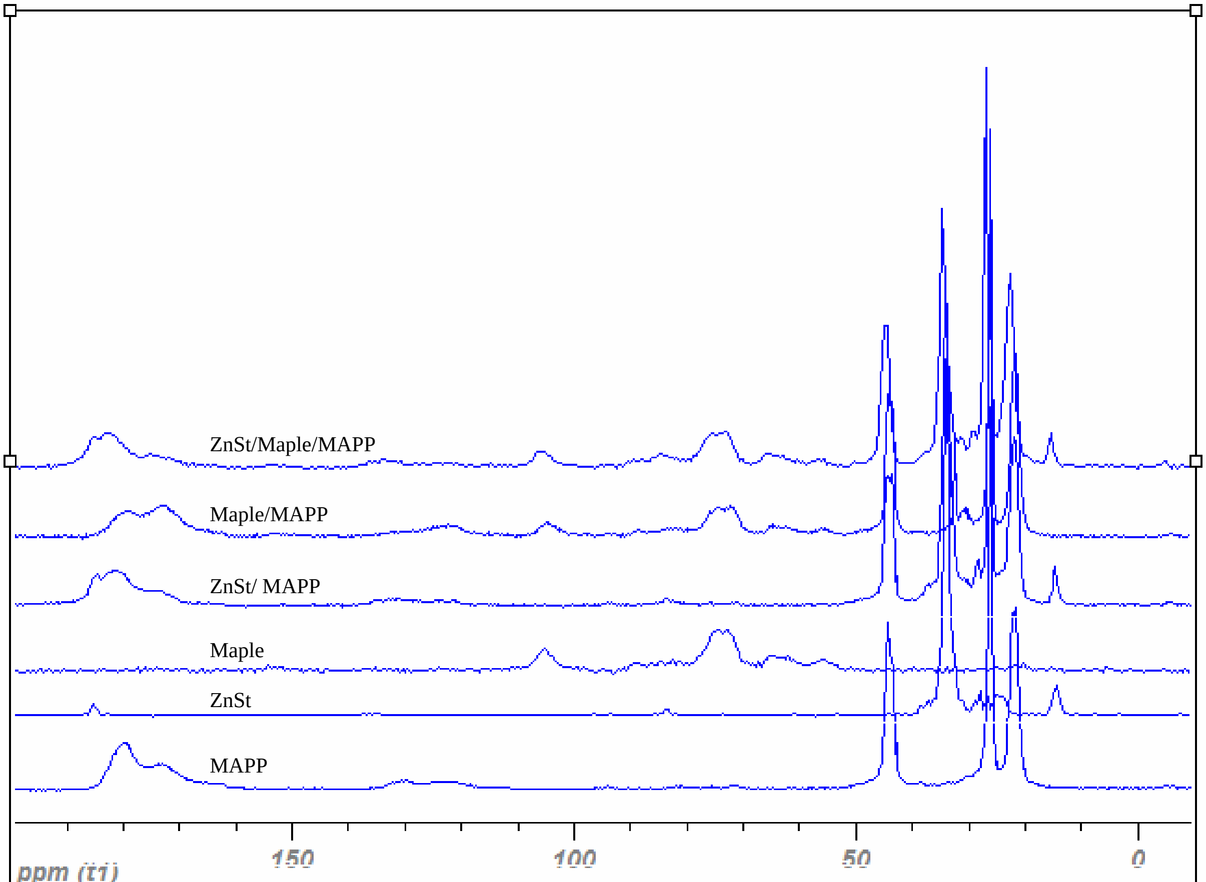

Figure 11: ^{13}C NMR of ZnSt/Maple/MAPP blend

Durable Wood Composites for Naval Low-Rise Buildings

Development of a Coating Technology for Wood Plastic Composites

Siding and Trim Components

Task: S4) Development of finishes for wood/plastic composites

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Abstract

With the increasing use of wood plastic composites (WPCs) in exterior applications, the use of surface coatings for WPCs is one promising route to improve durability. Developing a suitable coating technology for WPCs requires a thorough understanding of WPCs surface chemistry and wettability in particular, since these properties directly relate to paint adhesion. The first objective of this project was to characterize WPC surface properties and their impact on paint adhesion. Furthermore, for neat thermoplastic substrates, paint adhesion is often very low but can be greatly improved by surface treatments. The second objective of this research was therefore to evaluate the adequacy of common surface treatments for improving paint adhesion to WPCs. With these objectives in mind, 8 WPC formulations were extruded, and their surface characterized before and after selected surface pretreatments. Specifically, surface chemistry and wettability were evaluated using attenuated-total-reflection FTIR (ATR-FTIR) spectroscopy and dynamic contact angle analysis with water. Paint adhesion was also determined from an 180^o Peel test.

Untreated WPCs exhibited heterogeneous hydrophobic surfaces of low surface energy (31.5 mJ/m^2). Paint adhesion to untreated WPCs (177-309 N/m) was intermediate to that of neat polyolefins (126-48 N/m) and neat wood (526 N/m). Paint adhesion correlated with contact angle hysteresis revealing the importance of surface roughness and chemical heterogeneity to the adhesion mechanisms. Surface pretreatment with oxygen plasma, flame, ultraviolet (UV)-Benzophenone (BP) and chromic acid were all successful at increasing paint adhesion to WPCs. The chromic acid (637 $\pm$ 88 N/m) and oxygen plasma (516 $\pm$ 116 N/m) were the most efficient treatments raising paint adhesion to WPC to levels similar or higher than that to wood. A combination of surface oxidation and roughening were found to be responsible for the paint adhesion enhancement.

Either treatment could be implemented industrially, by adding a post extrusion treatment step on the extrusion line. While the chromic acid treatment may be more economical than the plasma treatment, it is environmentally more adverse.

Introduction

Although fundamental knowledge exists on the adhesion of coatings to wood and also to polyolefins there is currently little information on the adhesion and surface properties of wood plastic composites WPCs (Back 1991; Ryntz 1998). Surely though, the presence of low surface energy polyolefins in WPCs will impart surface properties that are unfavorable to the adhesion of coatings. In addition it is likely that the surface properties of WPCs are dependent on their composition, such as polymer and additives. The first part of this project examines in detail the surface chemistry, wettability and paint adhesion of a series of WPCs. By probing relationships between surface properties and coating adhesion on WPCs, and also the impact of formulations on these properties, an understanding of adhesion mechanisms is then provided. Understanding surface and adhesion properties then allows for selecting potential methods for improving paint adhesion to WPCs. Indeed, a survey of the literature and industrial practices for painting or bonding polyolefins shows that polyolefin surfaces need to be pretreated prior to adhesive or coating application in order to develop proper adhesion. In particular surface pretreatments with

flame, chromic acid, ultra-violet (UV) radiation and oxygen plasma are efficient practices to enhance adhesion of polyolefins. These pretreatments generally oxidize and/or roughen polyolefins. Specifically, the oxygen plasma causes carbon-carbon chain scission in PE (Drnovska et al. 2003), crosslinking in PP (Bhat and Upadhyay 2002) and incorporation of oxygen moieties. Flame treatment generates alkoxy, peroxy and hydroperoxy groups that react with the polyolefins in a free radical pathway thereby forming reactive substrates (Strobel et al. 1995). Benzophenone (BP), when photo-excited by UV radiations, undergoes reactive collisions with the polyolefins creating surface active polyolefins (Ranby et al. 1999). Chromic acid etching, in addition to roughening plastic surfaces, leads to the formation of polar groups on polyolefins (Blais et al. 1974). Furthermore, these treatments favorably enhance the surface polarity and bondability of wood (Back 1991), (Nussbaum 1993), (Mahlberg et al. 1999), (Podgorski et al. 2000). Thus, it is not a surprise that some of these treatments have been found to improve adhesion to WPCs. In fact, Akhtarkhavari group reported improvement in paint adhesion after treating WPCs with corona (Akhtarkhavari et al. 2004). Gardner et al (2005) evaluated the bond strength of epoxy bonded WPCs and reported an increase in dry and wet adhesive shear strength after sanding and flame treatment (Gardner et al. 2005). In this case, the dry adhesive shear strength of the PP-composite was similarly improved by sanding and flaming, about 4 fold (2.50 MPa) compared to the untreated WPC surface. While these studies confirm that surface treatments can help adhesion to WPCs, a systematic and comprehensive evaluation of WPC surface activation methods is lacking. Consequently, the second part of this project screens the efficacy at improving paint adhesion to a series of surface treatments. Concurrently the surface properties of treated WPCs are evaluated so as to further gain insight on the adhesion mechanisms in action. This comprehensive assessment of surface activation methods and coating adhesion on WPCs will allow recommending an adequate coating technology for WPCs.

Materials and Methods

WPC sample preparation

60 mesh pine (*Pinus spp.*) and maple (*Acer spp.*) flour was obtained from the American Wood Fibers Association. High density polyethylene, HDPE, having a melt index of 0.40 g/10min and density 0.95 g/ml, and polypropylene, PP, with a melt index of 4.0 g/10min at 230^{o}C were obtained from Innovene Inc. and Equistar respectively. In addition, Maleic anhydride functionalized polypropylene, MAPP, with a density of 0.93g/ml and free maleic anhydride content <0.9%, was provided by Honeywell. A commercial polyester based lubricant (OP100) and talc from Honeywell and Luzenac America Inc. respectively were used in all formulations. A 2^3 factorial design was utilized to design eight WPC formulations so that the impact of polymer choice (HDPE vs. PP), wood choice (pine vs. maple) and coupling agent could be evaluated (Table 1).

Table 1. WPC formulations according to 2^3 factorial design

Wood Flour		Polyolefin		Lubricant	MAPP	Talc
Type	Wt (%)	Type	Wt (%)	Wt (%)	Wt (%)	Wt (%)
Pine	59	HDPE	33.8	1	2.3	4
Maple	59	HDPE	33.8	1	2.3	4
Pine	59	PP	33.8	1	2.3	4
Maple	59	PP	33.8	1	2.3	4
Pine	59	HDPE	36.1	1	0.0	4
Maple	59	HDPE	36.1	1	0.0	4
Pine	59	PP	36.1	1	0.0	4
Maple	59	PP	36.1	1	0.0	4

The materials were first dry blended. Extrusion was then conducted on a 35 mm intermeshing twin screw extruder (Cincinnati Milacron) operating at a 5-8 rpm screw speed and at 3.45-5.52 MPa melt pressure and equipped with a water-spray cooler. The barrel and die temperatures were 163^{o}C and 171^{o}C for HDPE formulations and 185-193^{o}C and 185^{o}C for PP formulations respectively. Rectangular sections (38mm x 10mm) were thus extruded and small specimens (36x9x1 mm^3) were sliced and milled from the center of the WPC cross-sections. In other words, the 1 mm thick WPC specimens had faces (9mm X36mm) that came from the bulk WPC lumber. In machining specimens from the bulk lumber, it was intended to sample uniform, homogeneous surfaces whose properties would be independent of processing. For each specimen, the 9x36 mm^2 surfaces were refreshed and cleaned according to ASTM D2093. Specifically, sanding with 320 grit sandpaper was followed by wiping with lint free cotton cloth and washing in acetone, after which the samples were dried for 1 hour period at 40^{o}C and stored in dessicators with drierite overnight. All the surface characterizations were performed the day after sample conditioning ensuring that no significant aging would take place for any formulations. For each formulation 4 replicates specimens were prepared to undergo the series of surface characterization and another 4 specimens were prepared for acrylic coating application and peel adhesion test. For both surface characterization and the adhesion test, neat polyolefin and neat wood specimens were also prepared and evaluated for comparison. In addition, for each formulation, another 8 replicate specimens were prepared to undergo the surface treatments selected and be evaluated for both surface properties and peel adhesion.

Selected surface treatments

Based on the literature on neat polyolefins, four surface activation methods were selected to pretreat WPCs. These were oxygen plasma, chromic acid, flame treatment and UV/BP treatment.

Oxygen plasma treatment:

Plasma was generated in a cylindrical reactor with a radio frequency (13.56MHz, ASTM D 6105-04) coil, at room temperature, 100 watt power and $0.2x10^{-6}$-$2.1x10^{-6}$ MPa base pressure. The design of the reactor is given elsewhere (Shepsis et al. 2001). All four replicates were treated in a single run. The specimens were firmly end-attached on a double sided scotch tape wrapped on a steel rod running through the middle of the reactor (along the horizontal axis). HDPE formulations were treated at $0.013x10^{-3}$ MPa pressure, 52sccm oxygen flow rate and 30min treatment period(Drnovska et al. 2003). PP formulations were treated at $0.011x10^{-3}$ MPa pressure, 10sccm oxygen flow rate and 10min treatment period (Bhat and Upadhyay 2002). To avoid contamination and aging, treated specimens were transported in clean glass vials and characterized within 150min of treatment.

Chromic acid treatment

A chromic acid solution was prepared as per ASTM D-2093. The specimens were immersed in fresh chromic solution under constant stirring at 70^{o}C for 2min. The specimens were subsequently washed in distilled water for 20min, dried in oven at 40^{o}C for 1 hr, conditioned in desiccators overnight and carried in glass vials for characterization within 24 hrs.

Flame treatment

Air (2.9 kPa) and natural gas (3.7scfm) were mixed in a venturi-tube to generate flame from a 'T' type utility ribbon burner (Ensign Ribbon Burners LLC, NY). The burner was packed with four layers of corrugated sheets to produce uniform flame cones. Specimens were placed side-by-side on a steel plate at a distance of 12mm from burner-edge and manually moved at a speed of ~0.3m/s in flame.

UV/ BP treatment

Test specimens were dipped into an Acetone / Benzophenone (BP) solution (5% by wt) (Castell et al 2004) for 1 minute. A thin film of BP was thus deposited on the WPC surface. BP coated specimens were irradiated for 2min, each side, under metal halogenide lamp (Heraeus 380 watt) at 20cm substrate-to-source distance(Castell et al. 2004). Exposed specimens were washed with acetone (to remove extra BP) and kept in glass vials wrapped with aluminum foils overnight.

Surface Characterization Techniques

Surface chemistry was first characterized using attenuated total reflection Fourier transform infrared spectroscopy. A Thermo Nicolet Continuum model, equipped with a MCT-A detector and a ZnSe crystal and using an incident angle of 45 ± 5^{o} was used. 560 scans were acquired for each specimen in the IR region with a 4 cm^{-1} resolution. The spectra were analyzed with the Omnic 5.0 software. In particular, an index for surface cellulosic hydroxyl groups (Eq. 1) was obtained by normalizing the cellulosic hydroxyl peak intensity at 1023 cm^{-1} to the polyolefinic

νC-H stretching peak intensity at 2912 cm $^{-1}$ (Stark et al. 2004). This method provides an approximate measurement of the wood surface content, or "wood index".

$$Wood.Index_{OH/C-H} = \frac{I_{1023}}{I_{2912}} \qquad (1)$$

Following, ATR-FTIR measurements, the specimens were immediately characterized by dynamic contact angle analysis (DCA) for wettability. A Cahn 322 model was used and the probe liquid was type II deionized water. The DCA stage speed was 194 µm /s . Using the Whilelmy plate principle (Eq. 2), the advancing and receding water contact angles, θa and θr, could be extracted at the air-water-sample interface, by linear extrapolation of the advancing and receding force-displacement curves:

$$F = \gamma_l p \cos\theta \qquad (2)$$

In equation 2, F is the force at zero immersion, γ_L is the probe liquid surface tension, 72.8mJ/m^2 in the case of water, p the wetted sample perimeter of sample and θ the contact angle. The wetting hysteresis (Eq. 3) is also measured from the advancing and receding contact angles θ_a and θ_r (Chen et al. 1991).

$$\Delta W = \gamma_L(\cos\theta_r - \cos\theta_a) \qquad (3)$$

For some selected WPC formulations, critical surface tension (γ_C) was also determined with Zisman plots. In this case, a series of probe liquids consisting of 40%, 50%, 60% and 80% w/w acetic acid solutions in water were prepared to span a liquid surface energy from approximately 32 to 42 mJ/m^2 as measured with a glass slide (Gardner et al. 1991). For each probe liquid, a linear regression of the measured cos θ_a against the liquid surface tension was extrapolated to a 0 contact angle at which γ_C was defined (Adamson and Gast 1997).

Adhesion test

A separate set of 4 replicate specimens per formulation and surface treatment was prepared for the adhesion test. Coating adhesion was evaluated on a water-based white acrylic primer that was specifically formulated by Drew Paints. The acrylate primer was applied (0.28-0.41 mm) on the specimens using a wire wound draw down bar (#32). A strip of cheese cloth (9 mm wide) was then placed on the wet primed surface according to ASTM D6083. The assembly was then cured at room temperature (23^{o}C) for 1 hr, after which a second layer of primer was applied and cured for 48 hrs. The free end of the cloth was wrapped with a mask tape and a 180^o peel test was conducted at a crosshead speed of 2.0 cm/min by peeling the cloth from the surface (Ranby 1995). The peel test was performed on an Instron (model 4426) testing machine using a tensile grip.

Statistical analyses

An analysis of variance, ANOVA was conducted at an α level of 0.5 to evaluate the effect of polymer choice, wood species choice and coupling agent on all the properties measured namely

OH/CH content, advancing contact angle, receding contact angle, wetting hysteresis and peel load.

Results and Discussion

Characterization of WPC surfaces and adhesion to a water-based acrylic coating

Table 2 presents the parameters that portray WPCs dynamic wettability (advancing contact angle, receding contact angle and wetting hysteresis), surface hydrophilicity (OH/CH) and the adhesion of the water-based acrylic coating on WPCs (peel load). In terms of adhesion strength, the peel load of an acrylic coating of WPCs is low, at least compared to that obtained on a wood substrate. The peel load of the acrylate coating on WPCs is approximately half (168-309 N/m) that observed on Maple (524 N/m). It is however higher than that measured on the neat polyolefins especially in the case of HDPE which is notoriously difficult to adhere to (48 N/m).

Table 2. Surface characteristics of WPCs and adhesion to an acrylic coating

Formulation	OH/CH	θ_a (^{o})	θ_r (°C)	Wetting Hysteris (mJ/m^2)	Peel Load (N/m)
HDPE / Pine/ MAPP	2.32 ± 0.15	95±5	41±3	67±15	177±21
HDPE /Maple/ MAPP	1.52 ±0.05	95±5	35±7.5	63±9	168±13
PP/ Pine/ MAPP	1.90 ± 0.03	102±6	29.5±9	82±16	232±9
PP/ Maple/ MAPP	2.56±0.08	101±4	24±8	80±8	249±9
HDPE / Pine	1.20±0.24	99±3	22.4±7	79±2	218±16
HDPE / Maple	2.75±0.04	98±3	20±2	78±3	217±23
PP / Pine	2.18±0.26	99±2	24±13	85±12	290±24
PP / Maple	2.80±0.01	105±1	18±9	90±2	309±20
Maple	3.88 ±0.77	75[a]	-	-	524±64
PP	0.0	95 [b]	-	-	126±35
HDPE	0.0	87 [c]	-	-	48±1

This rather low adhesion may stem from the poor wettability of WPCs to the water-based acrylic coating. Indeed, the water contact angle for WPCs indicates a non-wettable, hydrophobic surface (95±5 ^{o} to 102±6^o) , closer to that of plastic than to that of Maple (75^o) or Pine (46^o) (Mohammed-Ziegler et al. 2004) (Table 2). In addition, the critical surface tension of WPC formulations as determined from Zisman plots (not shown here) is around 31.5 mJ/m^2 , again

similar to that of polyethylene at 31.0 mJ/m^2 and well below that of Maple(Ryntz 1998; Mohammed-Ziegler et al. 2004) or Pine at 46.6 mJ/m^2 and 58.5 mJ/m^2 respectively. The energetic characteristics of WPCs are therefore similar to those of polyolefins explaining the low peel adhesion measured with a water-based acrylic coating (Table 2). Interestingly though, a strong linear correlation (r^2=0.89) between water contact angle hysteresis and the adhesion strength of the acrylate coating onto the untreated WPCs is observed (Fig. 1). In other words, 89% of the difference in coating adhesion observed among WPC formulations can be explained by the variation in the wetting hysteresis of WPCs with water. Such a correlation has been observed before on aged polyolefins and also on a series of epoxy adhesives (Konar et al. 1992; Bistac et al. 1998). This indicates that surface heterogeneity, namely chemical and topographical heterogeneities are major players in the adhesion mechanisms of acrylic coatings to WPCs.

To better understand the respective importance of topographical and chemical heterogeneity on the wetting hysteresis and thus the coating adhesion, the dependency of wetting hysteresis and peel load on the advancing and receding contact angles can be examined. Indeed, for an hydrophobic surface, roughness increases the advancing contact angle (Kendall 2001). Similarly, for an heterogeneously hydrophobic surface, the receding contact angle is expected to decrease with both roughness and chemical heterogeneity (Lee et al. 1998).

In Fig. 2, the relationships between water advancing contact angle and both wetting hysteresis and peel load are presented. Positive linear correlations (R^2= 0.67 and R^2=0.66) are observed in both cases. In other words, an increase in advancing contact angle explains to a large extent an increase in wetting hysteresis and peel load. The first relationship showing an increase in contact angle along with an increase in wetting hysteresis is expected if surface roughness is the main contributor to the variations in contact angle. Again, the Wenzel model of surface roughness proposes that roughness increases the apparent advancing contact angle for hydrophobic surfaces. Concomitantly an increase in surface roughness will induce an increase in wetting hysteresis. On the other hand, the second relationship showing that an increase in contact angle is related to an increase in peel load is not expected. In fact, one would expect the opposite as low wettability leads to low adhesion. Only with the surface roughness in mind, can one comprehend the positive relationship between advancing contact angle and peel load. Indeed although detrimental to wettability in the case of hydrophobic WPCs, surface roughness can provide a greater area of contact between the liquid coating and the surface thereby allowing for the development of higher interfacial adhesion. Surface roughness can also contribute to adhesive peel strength by providing mechanisms for viscoelastic deformation of the plastic surface during the peel test. Polyolefins are highly deformable and prone to viscoelastic deformation that allows for large energy dissipation during a peel test and therefore a large practical work of adhesion. Finally, higher surface roughness may favor mechanical interlocking at the WPC/coating interface, further contributing to the overall adhesion.

While surface roughness clearly plays a strong role in adhesion of an acrylic coating to WPCs, the surface chemistry and chemical heterogeneity in particular may also contribute to the adhesion of the acrylic coating to WPCs. In Fig. 4, the wetting hysterisis and peel load dependency on chemical composition via OH/CH ratio or wood index is examined. While there is no clear relationship between the surface wood index, and either wetting hysteresis or peel load, an overall ascending trend is observed. In other words, WPC surfaces with a high “wood

index" are also those with a high wetting hysteresis and peel load. Therefore, surface chemistry also plays a role in the surface adhesion of WPCs; however its role is complex. An alternate way to envision how surface chemistry and adhesion may be related in these systems, is to evaluate the impact of surface chemical heterogeneity on the wetting hysteresis. In particular, the advancing and receding contact angles of WPCs can be plotted against an estimated fractional coverage of hydrophobic material (Fig. 4) (Lee et al. 1998). In Fig. 4, the fractional coverage of hydrophobic moieties was estimated from the surface wood index. For comparison, the Chappuis model that describes the advancing and receding contact angles of heterogeneous hydrophobic/hydrophilic surfaces is simulated for WPCs (Fig. 5) (Lee et al. 1998). For such heterogeneous hydrophobic surfaces, the Chappuis model predicts that the receding contact angle increases significantly with higher hydrophobic fractional coverage while the advancing contact angle remains constant close to that of the hydrophobic material (Lee et al. 1998). This is exactly what is observed in Fig. 4. As the fractional coverage of hydrophobic material increases, that is as the "wood index" decreases, the receding contact angle increases significantly while the advancing contact angle remains rather constant. This behavior therefore suggests that chemical heterogeneity contributes to the variations in receding contact angle and wetting hysteresis that are observed among formulations. Of course surface roughness is also likely to contribute to variations in receding angle. Indeed, by allowing water to be trapped in the surface micropores upon wetting, surface roughness would also lead to lower receding contact angles. And in the case of WPCs, surface roughness and "wood index" may be closely related. This is significant because variations in receding contact angle also explain a great deal of wetting hysteresis (R^2=0.67) and also peel load (R^2=0.55) (Fig. 5). The lower the receding water contact angle on WPCs, the higher the wetting hysteresis and the higher the adhesion of the acrylate coating on WPCs.

In WPCs, the surface chemical and topographical heterogeneities therefore appear to be closely related to the adhesion of an acrylic coating. Both parameters are closely intertwined in their effect on coating adhesion. However, surface roughness likely contributes greater interfacial area, mechanical interlocking and possibly viscoelastic energy dissipation mechanisms. Chemical heterogeneity may contribute more polar interactions. With this understanding of the surface properties of WPCs and of the parameters that govern coating adhesion for WPCs, one can then evaluate promising surface treatments to improve the adhesion of water-based coatings to WPCs. The efficacy of surface pretreatments is reviewed next along with their effect of WPC surface properties.

The Efficacy of Surface Pretreatments at improving coating adhesion to WPCs

Table 3 summarizes the effect of the four surface treatments on the surface chemistry and dynamic wettability of WPCs. The impact of these surface treatments on the adhesion of the water-based acrylate coating is also presented. For treated and untreated surfaces, the measured properties are compared and grouped according to a Tukey test. The letters (A,B…) in Table 3 are the result of this grouping for all WPC properties from high to low, in alphabetic order.

Table 3: Effect of surface treatments on the surface properties and adhesion of an acrylate coating on WPCs

Treatment	O=C/C-H	Wood index	θ_a(°)	Relative Hysteresis	Peel Load (N/m)
Untreated	2.06 ± 0.70 (B)	2.11 ± 0.77(A)	100 ± 7 (C)	0.77 ± 0.15 (C)	232 ± 56 (E)
Flame	1.83 ± 1.06 (B)	1.70 ± 0.56(B)	104 ± 14 (C)	0.99 ± 0.04 (A)	381 ± 94 (D)
Chromic	1.63 ± 1.6 (B)	1.01 ± 0.46 (C)	120 ± 19 (B)	1.00 ± 0.00 (A)	637 ± 88 (A)
UV/BP	1.89 ± 1.8 (B)	1.25 ± 0.69(C)	140 ± 10 (A)	0.97 ± 0.07 (A)	466 ± 107 (C)
O_2 Plasma	3.14 ± 1.73 (A)	1.97 ± 0.91 (A)	35 ± 14 (D)	0.86 ± 0.18 (B)	516 ± 116 (B)

The examination of the peel load reveals that all the surface treatments significantly improve the adhesion of the acrylic coating to WPCs (Table 3). This is true regardless of the WPC formulation considered as demonstrated in Fig. 6. The chromic acid treatment is by far the most efficient at increasing the adhesion of the acrylic coating to WPCs. The O_2 plasma treatment and the UV/BP treatments then follow, above the flame treatment. Most importantly, both the chromic acid and the plasma treatments allow reaching adhesion levels similar or higher to that obtained on Maple (Table 1). Specifically, after plasma treatment, the peel strength of the coating to WPCs is as high as that previously obtained on Maple. After chromic acid treatment of WPCs, the peel strength of the coating to WPC significantly exceeds that obtained on Maple. The other treatments do not allow reaching adhesion levels as high as that on wood. Therefore, both the O_2 plasma and the chromic acid treatments are possible surface treatments to raise the coating adhesion of WPCs to expected levels for exterior applications.

When trying to understand the adhesion mechanisms imparted by the surface treatments on WPCs, correlations between surface chemistry, dynamic wettability and peel load can again be evaluated. By contrast to the relationships that were clearly observed between dynamic wettability and coating adhesion for untreated WPC formulations, no clear relationships could be established among treated WPCs. However, some distinct features of WPC surface properties after O_2 plasma and chromic acid treatments point to the adhesion mechanisms in action.

Specifically, the O_2 plasma treatment appears to significantly oxidize WPC surfaces as evidenced by the higher surface O=C/ CH ratio measured post treatment (Table 3). This increase in surface polarity is also portrayed by the improved wettability of the O_2 plasma treated WPCs. Again the plasma treatment is the only treatment to significantly decrease the water contact angle on WPC from approximately 100° to a very low 35° (Table 3). Therefore, the plasma treatment, by oxidizing the surface of WPCs, greatly enhances its wettability to water-based coatings. In addition, greater surface polarity also leads to greater polar interactions between the acrylic coating and the WPC surface. This likely explains the two-fold increase in the adhesion of the coating to WPCs after plasma treatment. On the other hand, the chromic acid treatment along with the other treatments do not significantly oxidize WPC surface as evidenced by the similar O=C/CH ratio than for untreated WPCs. Yet, they appear to modify the surface composition of WPCs, namely by decreasing the wood index ratio. In other words, the chromic acid and UV/BP cause an increase in plastic concentration on the surface, likely due to plastic melting and flowing at the temperatures used. Not surprisingly then, the wettability of such surface treated WPCs is further depressed as indicated by the much higher advancing contact angles (Table 3). Again, surface roughening may well be the underlying factor that induces an increase in advancing contact angle, along with an increase in coating adhesion. And indeed this increase in

advancing contact angle is again concurrent with an increase in wetting hysterisis. To further verify this behavior, the surface topography of WPC surfaces after treatment was assessed by profilometry (Fig. 7). Although qualitative, these data clearly show that the chromic acid, more than any other treatments, significantly increases the surface roughness of WPCs. Scanning electron microscopy pictures of the WPC surfaces before and after chromic acid treatment confirms (Fig. 8) that the chromic acid treatment significantly roughens the surface of WPCs. In the case of chromic acid treated WPCs then, adhesion enhancement mechanisms likely relate to surface roughness and involve greater interfacial area, mechanical interlock and viscoelastic energy dissipation.

Conclusions and Recommendations

The surface properties and the adhesion of an acrylic coating on a series of WPC formulations were examined. For untreated WPCs, it was found that the adhesion of the acrylic coating was approximately ¼ to ½ that on Maple, depending on the formulation. Low adhesion levels were ascribed to the hydrophobic nature of WPCs, with surface energy levels similar to those of WPCs. In addition, a strong linear relationship was identified between water contact angle analysis and the peel strength of the acrylic coating on the WPC surface. This relationship was interpreted in terms of surface roughness and surface chemical heterogeneity. The higher the surface roughness and chemical heterogeneity, the greater the adhesion of the coating on WPCs. To improve the adhesion properties of WPCs, four surface treatments were performed. These were an O_2 plasma, chromic acid, benzophenone/UV and flame treatments. All the treatments significantly improved the adhesion of the acrylic coating to WPCs although to different levels. Namely the chromic acid treatment yielded coating adhesion levels to WPCs significantly higher than those obtained on neat Maple. The Oxygen plasma treatment yielded coating adhesion levels similar to those on neat Maple. The other treatments were less efficient. While the Oxygen plasma treatment was effective by improving surface polarity and wettability, the chromic acid treatment operated by increasing surface roughness. As a result, both the chromic acid and the Oxygen plasma treatments can be employed in a coating technology of WPCs. A coating technology would then consist of applying the particular surface treatment best suited for WPC producer, as an-on line post-extrusion step. After surface treatment, the WPC would need to be immediately primed with the acrylic coating and sold as a “primed and or paint-able WPC”.

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Figures

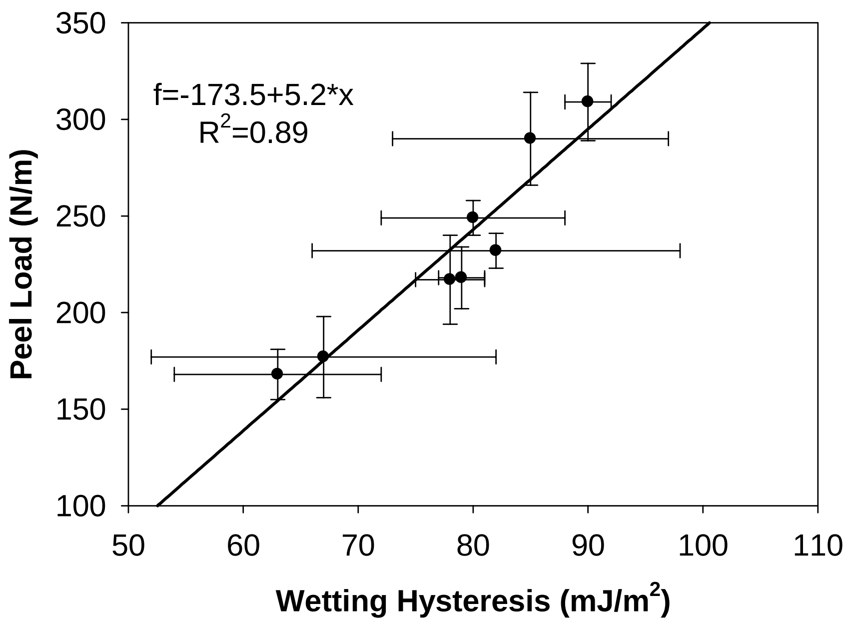

Fig. 1. The dependence of adhesive strength on the wetting hysteresis of WPCs with water

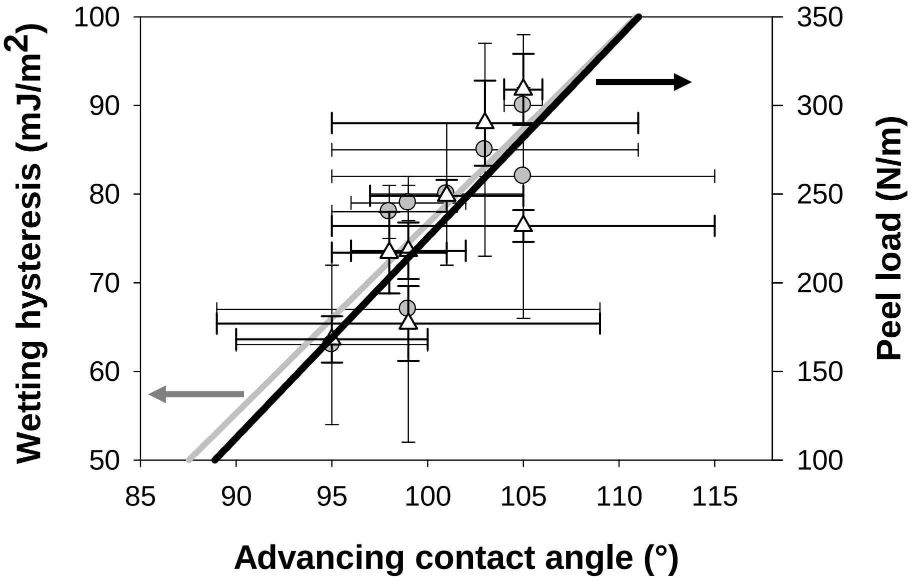

Fig. 2. The dependence of adhesive strength and wetting hysteresis on advancing contact angle

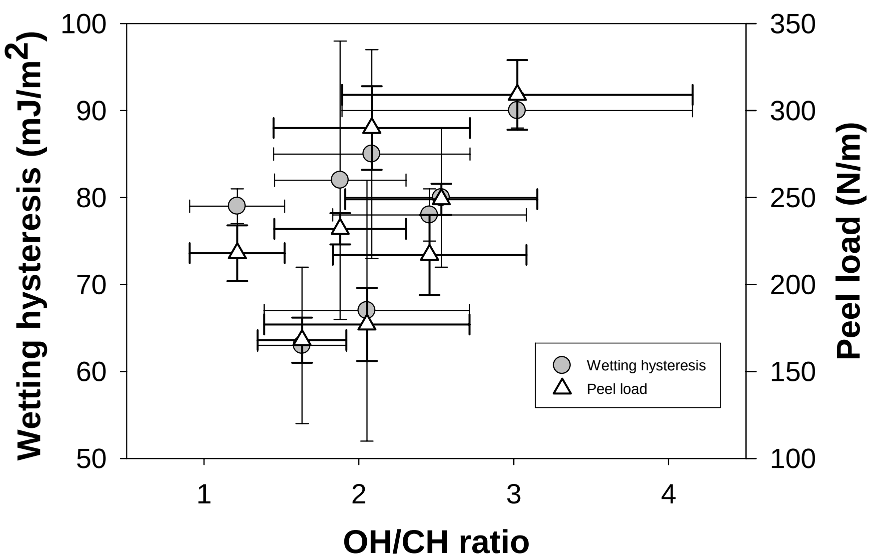

Fig. 3. The dependence of adhesive strength and wetting hysteresis on WPCs surface wood index

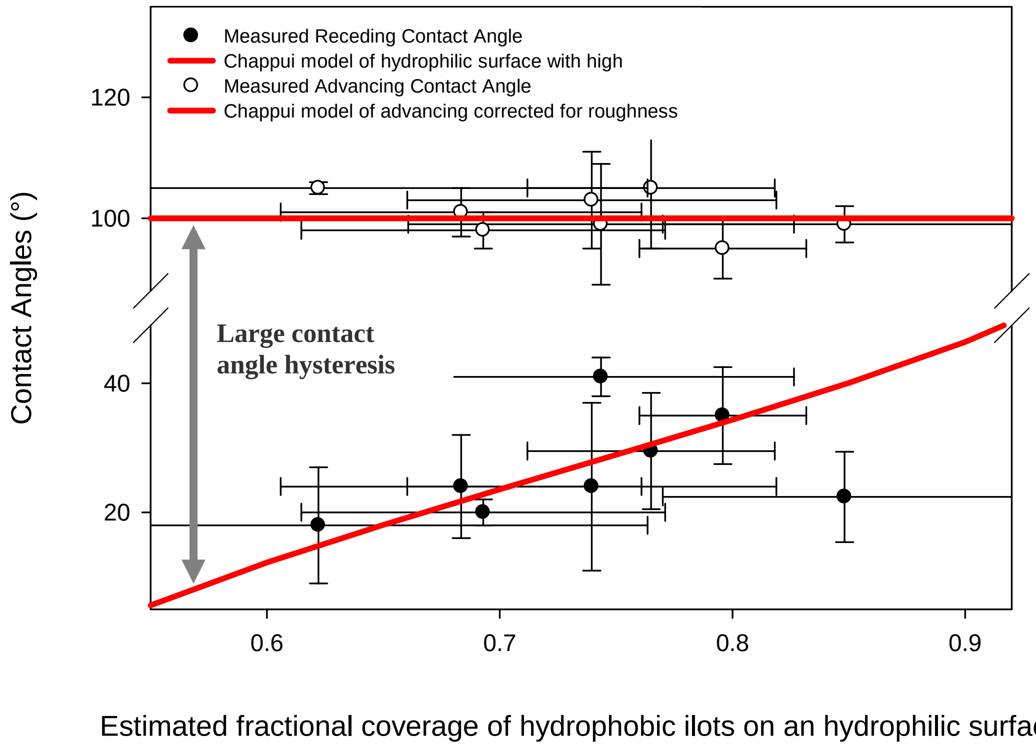

Fig. 4. Wetting behavior of WPCs as function of the apparent hydrophobic coverage

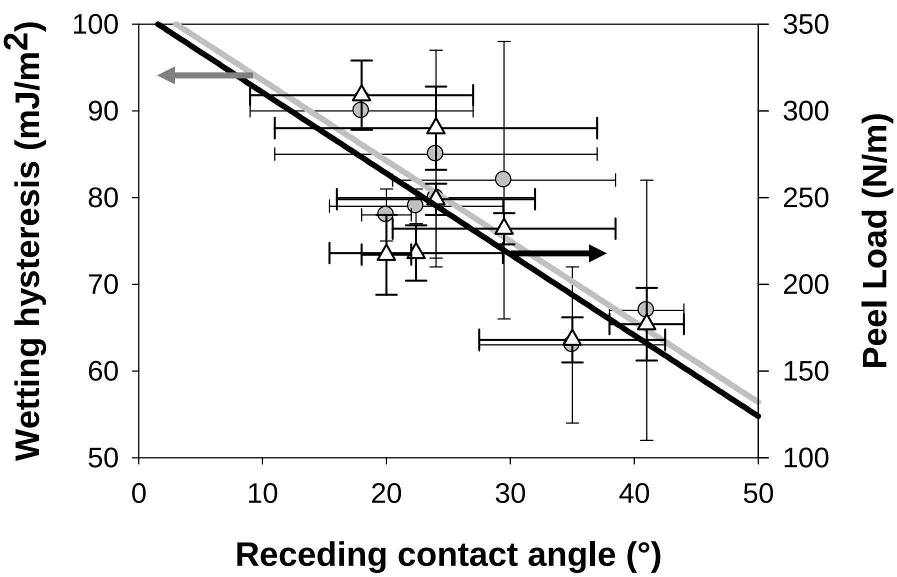

Fig. 5. The dependence of adhesive strength and wetting hysteresis on receding contact angle

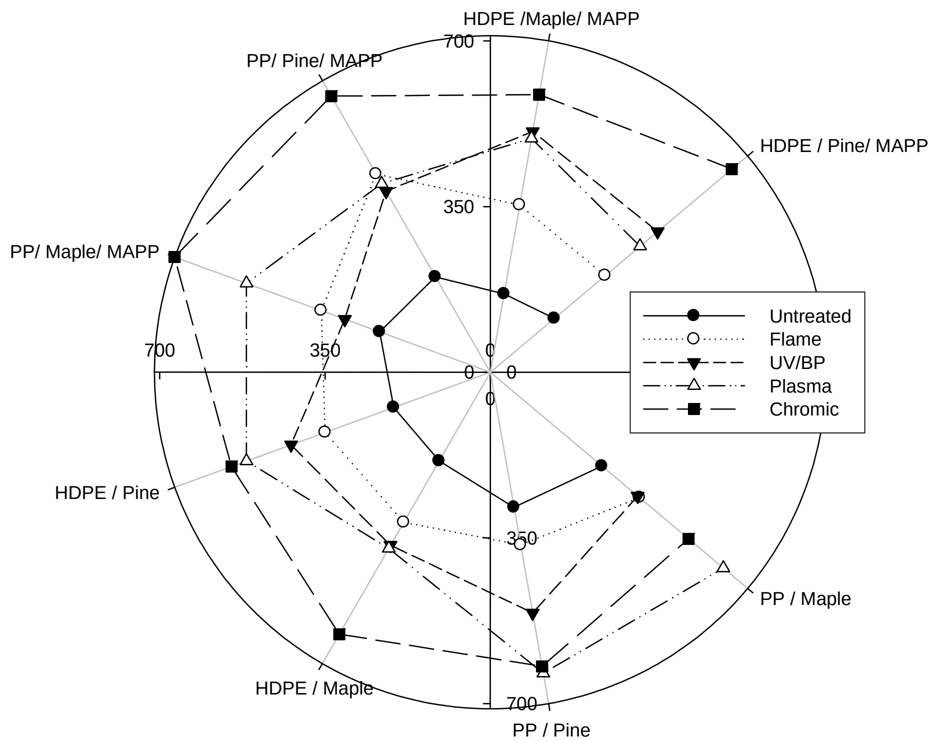

Fig. 6. The peel load of an acrylic coating on surface treated and untreated WPCs. While all the surface treatments enhance coating adhesion, the chromic acid surface treatment outperforms all the treatments closely followed by the O2 plasma treatment.

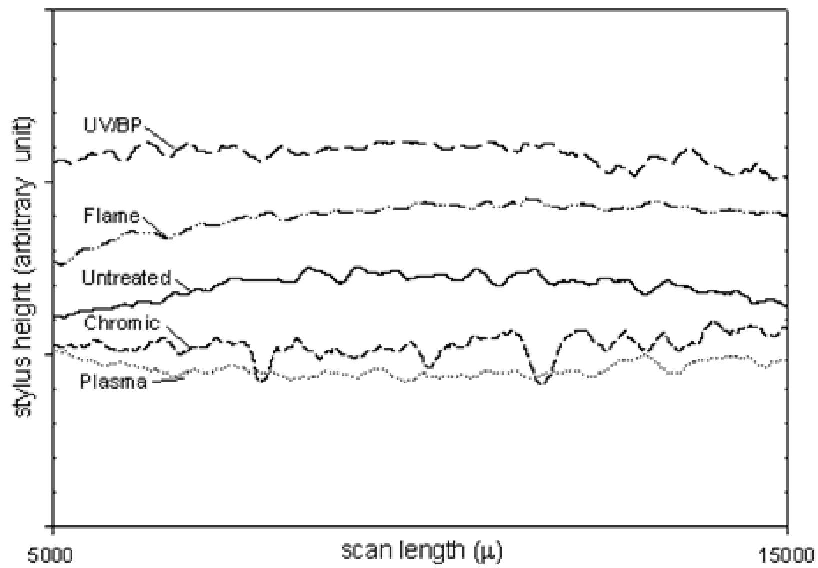

Fig. 7. Profilometry traces of WPC surfaces after various surface treatments, suggesting that the chromic acid most clearly enhances the surface roughness of WPCs.

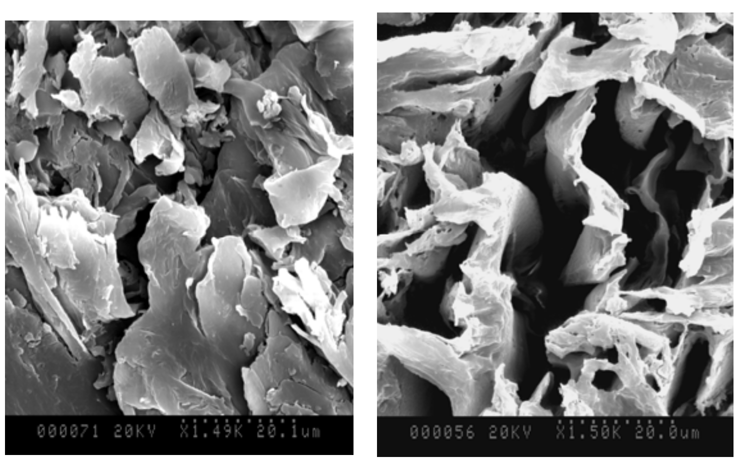

Fig. 8. SEM of untreated (left) and chromic acid treated (right) WPCs demonstrating the enhanced porosity of WPC surfaces after chromic acid etching.

Durable Wood Composites for Naval Low-Rise Buildings

Siding and Trim Components with Improved Weathering Performance

Siding and Trim Components

Task S5 – Siding and trim components with improved weathering performance

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Abstract

This report provides a detail chemistry of wood plastic composites (WPC) weathering for use as siding materials. The purpose of these studies (Parts A and B) were to get a better understanding of the aesthetic (color fade) and chemical changes that occur to the wood, plastic and additive components in WPC in order to develop an improved WPC formulation. WPC were weathered (natural and xenon-arc accelerated) and the weathered material assessed by a combination of UV-VIS colorimetry and spectroscopy, Fourier transform infrared spectroscopy, pyrolysis gas chromatography-mass spectrometry and differential scanning calorimetry (Part A). The surfaces of the weathered WPC were modified and underwent color changes. Surface lightness and discoloration increased with longer exposure time. High-density polyethylene (HDPE) based WPC had the least color change. In addition, it was observed that lignin was a contributing factor to WPC color change. A second study (Part B) was employed to examine the effect of wood species (poplar, ponderosa pine, Douglas fir, white oak and black locust) in WPC weathering. Species were selected based on lignin content, durability and wood color. WPC based on poplar gave the least amount of color change and degradation. The outcome of this study revealed that WPC formulations with enhanced weathering performance could be achieved with plastics with low thermal processing temperatures (such as HDPE) which minimize wood flour degradation and wood species with low lignin content and light color (such as poplar).

PART A:
Surface Chemistry and Color Change of Weathered WPC Composites

James S. Fabiyi, Armando G. McDonald, and Michael P. Wolcott

Summary

The effects of natural and accelerated (xenon and UV2000) weathering on the chemical and surface color changes of high density polyethylene based wood plastic composites were investigated. Color change, chromophores generation and the extent of oxidation on the surface of weathered WPC were monitored using colorimetery, UV-VIS spectroscopy and Fourier transform infrared spectroscopy, respectively. Pyrolysis gas chromatograph mass spectrometry was employed to determine the compositional changes that occur on the WPC surface. The study showed that for both natural and accelerated weathering, longer exposure time caused increased in color change (and surface lightness), more chromophores generation, higher oxidation, wood loss and higher non-wood content on weathered WPC surface. From this study, the relationships between chemical and color changes were established. Therefore modification of wood lignin might minimize changes in color fade of WPC used as outdoor material.

Introduction

There is a growing interest and demand for wood plastic composites (WPC) as both indoor and outdoor materials in the United States of America and some part of the world such as Europe and Australia. Despite of the increasing demand of WPC by the consumers, the growth in exterior applications of WPC has resulted in a great concern about their long-term weatherability and durability. The manufacturers are also concern about the crumbling and insurance/warranty claims of WPC [1]. Exposure of any polymeric materials such as WPC, wood or plastic to outdoor environment causes some modification of their surfaces, changes in external appearances and other properties. The changes in their properties are due to the effect of ultraviolet (UV) irradiation from sunlight which does cause some chemical reactions as a result of the chromophores present in the polymer. Some of these chromophoric elements are introduced into WPC from the metallic based additives and also during the degradation of wood whereby phenyl groups and carbonyl functional groups are generated. Consequent upon such reactions, polymer is enabled to absorb UV light, thereby resulting in photodegradation. The more the chromophoric elements are formed, the further the degradation because they have affinity to absorb the UV light. Several methods which include incorporation of additives such as pigments [2], antioxidants and light stabilizers [3] have been developed to ameliorate the weathering effects. However, the outcomes of the studies revealed that WPC still undergo photodegradation despite the incorporation of these chemical additives.

One must admit that several works have been conducted on the chemistry of plastic, wood and WPC weathering. Unfortunately, detail chemistry behind the color fading of WPC in service has not been addressed for WPC weathering. Most WPC weathering studies that have been conducted had considered the mechanical, physical and even chemical properties of WPC [2,4]. However, in-depth study on both qualitative and quantitative analysis of chemical composition changes of WPC has not been well analyzed. Understanding the detail chemistry of WPC

weathering is imperative to finding means of minimizing the effect of weathering on the products. Therefore, it is necessary to identify the initial chemical characteristic changes caused by combination of weathering factors especially UV, moisture and temperature change in WPC for better development of an effective and efficient method to produce improve weathering performance products.

Fourier transform infrared (FTIR) and differential scanning calorimetry (DSC) are common techniques used to evaluate the degradation process of polymeric materials [5]. Several studies on the WPC weathering were carried out, and their effects were analyzed by FTIR spectroscopy [1,2,6]. However, there has been no published article on the use of pyrolysis gas chromatography-mass spectrometry (Py-GC-MS) to characterize the chemical changes that occur during WPC weathering. Therefore, this study employed the use of Py-GC-MS to quantify the wood and non-wood content of weathered WPC. Py-GC-MS is a simple and rapid method to examine polymeric materials, particularly for lignin and plastics. It uses µg's of material and thermally cracks polymers into smaller volatile compounds and then analyzed by GC-MS. FTIR was used to chemically characterize the weathered HDPE-pine composites. The color changes and chromophoric elements generated on the WPC surface upon weathering were measured using colorimetry and UV-VIS spectroscopy.

The aim of this study is to determine the chemical and color changes that occur during the weathering process on HDPE/pine composites. It is also to establish the connectivity between chemical and color changes of weathered WPC.

Materials and Methods

WPC were prepared by premixing dried HDPE (31%, Equistar), pine wood flour (58%, 60 mesh supplied by American Wood Fibers), talc (8%), zinc stearate (2%) and ethylene bistearamide (EBS) wax (1%). This formulation is used because it is one of the most commonly recommended for commercial production by Wood Material and Engineering Laboratory, Washington State University (WMEL, WSU). Another reason for the selection of this formulation was based on the fact that it is easily extrudable without the incorporation of any coupling agent and lubricant. The premixed formulation was then extruded on a 35 mm conical counter rotating twin-screw extruder (Cincinnati-Milacron) to a profiled dimension of 3/8" x 1.5". The barrel and die temperatures were between 300 and 380°F. The extruded profiles were then surface machined to a thickness of 0.20" for weathering testing.

Accelerated and natural weathering of WPC. Accelerated weathering tests were conducted in a UVA2000 (Atlas) and xenon-arc (Q-Sun Panel) weatherometers that simulates the damages caused by sunlight, rain, and temperature. The WPC specimens (0.2" x 1.5" x 4") were subjected to an accelerated weathering procedure (average irradiance was 0.70 W/m^2 at 340 nm, chamber temperature of 70°C and water spray) according to the ASTM D 6662 standard [7]. Specimens for color and chemical characterization were collected at every 400 hours to a total of 2000 hours exposure time.

Natural weathering tests were conducted by exposing the WPC specimens (0.2" x 1.5" x 24") outside on a south-facing wall at an angle of 45° (Moscow, ID) following ASTM D 1425 [8]

starting in November 2004. The test specimens for outside exposure were collected on day basis for a total of 90 days of exposure. Average daylight in Moscow within the period of exposure was approximately 9-10 hrs/day for December 2004 to January 2005 and 12-13 hrs/day for February to March 2005. The average temperature ranged from 16 to 47°F in December 2004 and January 2005 and from 26 to 52°F in February and March 2005.

Color measurement and UV Spectroscopy. The surface color of weathered WPC specimens (at 3 locations) was determined in accordance with the ASTM 2244 procedures [9] using a StellarNet EPP2000 UV-VIS spectrometer, krypton light source (SL1, Stellar Net), with a diffuse reflectance fiber optic probe. This spectrometer software transforms spectral data into CIELAB color coordinates (L*, a* and b*). Lightness (*L*) and chromaticity coordinates (*a* and *b*) were measured for five replicate measurements/samples and the color change (ΔE_{ab}) determined. L*, a*, and b* color coordinates of each sample, before and after exposure to UV2000 and natural weathering testing, were calculated on the basis of a D65 light source as established by CIE [10]. Color change (ΔE_{ab}) was calculated using the following equation:

$$\Delta E_{ab} = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \quad \text{…………………………….(equation 1)}$$

where, ΔL^*, Δa^*, and Δb^* represent the differences between the initial and final values of L^*, a^*, and b^*, respectively. An increase in L means the sample is lightening (i.e., a positive ΔL^* for lightening and a negative ΔL^* for darkening). A positive Δa^* signifies a color shift toward red, and a negative Δa^* signifies a color shift toward green. A positive Δb^* signifies a shift toward yellow, and a negative Δb^* signifies a shift toward blue.

Chromophores generation was monitored based on the assumption that the chromophores concentration level correspond to the UV absorption level by UV-VIS spectroscopy. Diffuse reflectance UV-VIS spectra on naturally and accelerated weathered samples was recorded using a StellarNet EPP2000C UV-VIS spectrometer (190-850 nm) with a deuterium light source (SL3, StellarNet) also with a diffuse reflectance fiber optic probe.

FTIR spectroscopy. Changes in the carbonyl, vinyl and hydroxyl (OH from talc) regions during weathering were monitored by FTIR. Spectra were collected by ThermoNicolet Avatar 370 spectrometer (Thermo Electron Corporation Waltham MA, ZnSe crystal) mode. The measurements were made in transmission and Attenuated total reflection (ATR) mode and mathematically ATR and baseline corrected. The ATR technique was employed because solid materials were used. Thin slices of about 50-100 µm of WPC (vacuum dried) from three samples were analyzed. Each spectrum was taken as an average of 64 scans at a resolution of 4 cm-1. The carbonyl index (CI), vinyl index (VI) and hydroxyl index (HI) were calculated as the ratio of the peak intensity (absorption) at 1710-1735, 1630-1650 and 3676 cm-1 which are assigned to carbonyl (C=O), vinyl (C=C) and hydroxyl (OH) groups to that at 2916 cm-1 ($-CH_2$-scissoring peak) for HDPE.

Pyrolysis Gas Chromatography-Mass Spectrometry (Py-GC-MS). Wood derived compounds (lignin and few carbohydrates) were identified and quantified by Chromatography-Mass Spectrometry (GC-MS). About 1 g of samples was collected from the weathered (50-100 µm thick) surface was ground to 60 mesh particles and vacuum dried before subjected to Pyrolysis-

GC-MS analyses. About 50 µg of each sample (2 replicates) was then loaded into a quartz tube and pyrolyzed at 600^{o}C in a SGE Pyrojector II (Ringwood, Australia), coupled to a ThermoFinnigan PolarisQ GC-MS (San Jose, CA, USA). Separation of the volatile products was achieved on a ZB-1 capillary column (30 m, 0.25 mm) using a temperature ramp from 40^{o}C (2 min) to 300^{o}C (10 min) at 5^{o}C/min. The chromatograms and mass spectra were analyzed using the Xcalibur software package (San Jose, CA, USA). The wood content in the weathered WPC samples was quantified by pyrolysis-GC-MS by developing a calibration curve from the total peak areas under the wood derived peaks relative to the total peak areas under the polyethylene derived peaks based on tests of a series of WPC formulations of known wood content (0, 20, 56, 60 and 100% wood content for PE based WPC).

Results and Discussion

Color changes and chromophores formation of weathered WPC

Surface lightness (ΔL^*) and color change (ΔE_{ab}) of weathered HDPE/pine composites are illustrated in Table 1. WPC surface discoloration observed in this study provided the evidence of photodegradation. Color change (ΔE) and surface lightness (ΔL) increased upon weathering until 1200, 1600 and 2000 h for the xenon, UV2000 and outside weathered WPC respectively (Table 1). The results are consistent with other weathering studies [6,11].

Table 1. Color change and surface lightness of weathered HDPE/pine composites.

Exposure time (h)	**UV2000 weatherometer**		**Xenon-arc weatherometer**	
	Color change (ΔE)	Surface lightness (ΔL)	Color change (ΔE)	Surface lightness (ΔL)
400	6.8	2.0	24.0	15.9
800	10.8	7.5	29.0	22.8
1200	12.4	20.6	30.3	30.2
1600	16.6	9.9	20.9	26.4
2000	13.4	11.6	17.1	25.0

Outdoor exposure					
Exposure period (days)	15	30	50	70	90
Color change (ΔE)	12.4	6.4	7.5	8.2	8.9
Surface lightness (ΔL)	0.1	0.8	4.0	6.9	7.6

Ultra-violet (UV) absorbance spectra of the xenon weathered WPC was used to deduce the chromophoric elements (or electronic structure of molecules) generation during weathering, hence UV-VIS reflectance spectroscopy was employed to measure the UV absorbance spectra of the WPC. Figure 1 showed the UV irradiance absorbance of xenon weathered WPC increased with longer exposed time. The absorbance between 190 and 400 nm is associated with molecules containing π–electron systems, i.e. presence of unsaturated vinyl groups. However, there was no significant change in the UV absorbance between 1600 and 2000 h exposure. This may likely indicate that little or no change in the concentration of chromophores and vinyl groups occurred after 1600 h exposure in xenon weatherometer. Upon weathering, vinyl group formation

increased with time as evident in increased UV absorbance, thereby confirming increase in polymer chain scission.

HDPE based WPC has higher UV absorbance between 200 and 420 nm range and highest between 575 and 615 nm which are defined as UVC to UVA and visible, respectively (Figure 1). Since much of the electromagnetic radiations in the UVB and UVC regions are absorbed by the ozone layer in the stratosphere and most of the UVA radiation reaches the earth's atmosphere, it is expected that the radiation in the UVA region will have a greater effect on photo-aging than radiation from the UVB region [12]. It has been reported that cellulose absorbs UV light strongly between 200 and 300 nm, with a tail of absorption extending to 400 nm [12]. In a study, Hon and Ifju [13] explained that UV light cannot penetrate deeper than 75 µm while the visible light (400-750 nm) can penetrate up to 200 µm into wood. Although wood chemical components may not be sensitive to UV light of wavelengths longer than 340 nm, incorporation of polymer matrix might have enhances free radical formation in WPC at wavelengths longer than 340 nm.

Surface chemistry

A series of IR spectra for natural and accelerated (xenon and UV2000) weathered WPC were recorded. The spectra revealed that there are bands that are formed or disappeared while some increased or decreased on WPC surface upon longer exposure. The OH group at 1023-1050 cm-1 as some literature on WPC has reported has been assigned to wood cellulose. However, in this study, critical examination of this band was evident to be due to the contribution from both wood cellulose and talc content which WPC are produced from. The IR spectrum of talc is very neat and shows that the only two bands to identify talc are 1050 and 3676 cm-1. Therefore, it must be noted that 3676 cm-1 band is observed from the spectra, hence, the influence of talc to the 1025 cm-1 band cannot be over-emphasized. In fact, talc (3676 cm-1) became more exposed on WPC surface upon weathering relative to the unweathered WPC (Figures 2a, 3). The band at 1508-1512 cm-1 due to ether functional group from wood lignin disappeared upon longer exposure to any of the weathering regimes. This indicates that lignin degradation occurred on the weathered WPC surface. The lignin content absorbance peak of xenon weathered WPC disappeared at early exposure time while the outside exposed WPC had the lowest lignin degradation. More importantly, the band at 1650-1800 cm-1 is assigned to the carbonyl functional groups. This carbonyl region corresponds to: conjugated ketones (1700-1675 cm^{-1}), carboxylic acids (1725-1710 cm^{-1}), esters and aldehydes (1735-1720 cm^{-1}) [14]. The increased in carbonyl groups bands provided evidence that surface oxidation has taken place and in turn, it is an evident of photodegradation with extended exposure time. It also means that the material is vulnerable to further degradation because these carbonyl groups are photolabile [15]. The extent of WPC oxidation was determined by its total carbonyl functionality (1710-1735) and quantified by its carbonyl index (CI). The CI for the xenon and UV2000 accelerated weathered WPC increased from 7 to 12 and 7 to 32 % respectively, as a function of exposure time (Figure 2b, 3a), and this observation is consistent with that reported in the literature [6]. For the outside weathered WPC, the CI increased rapidly from 7 to 16 % after 70 days of exposure (Figure 3b).

Vinyl groups observed in WPC are most likely to be due to the non-wood content especially the HDPE, zinc stearate (ZnSt) and ethylene bistearamide (EBS) wax as evident in the aliphatic band at 2915-2850 cm-1. The vinyl functional groups in this case occurred because of the chain scission (breakage in the long aliphatic chain) of the non-wood content. The total absorbance of

bands between 1630 and 1650 cm-1 was used to quantify the degree of unsaturated (formation of double bonds) by vinyl index (VI). For the xenon and UV2000 accelerated weathered samples, the VI was shown to increase slightly from 3 to 6 and 3 to 25 % upon weathering (Figure 3a). For the outside weathered WPC the VI increased from 3 to 7 % after 90 days of exposure (Figure 3b). An increase in VI can be explained since the wood is attacked primarily and washed away with water runoff thus increasing in non-wood content at the surface.

Pyrolysis Gas chromatography-Mass Spectrometry (Py-GC-MS)
Figure 4 shows chromatograms of unweathered and xenon accelerated weathered HDPE/pine composites. Detail analysis of the chromatograms revealed that the unweathered WPC sample contained molecular fragments from both wood (lignin and carbohydrate) and non-wood content especially polyethylene. Upon weathering, the wood derived peaks decreased in intensity relative to the polyethylene derived peaks. On the other hand, almost all the peaks for HDPE remained even after weathering of the WPC. The HDPE derived peaks were ethane (C_2), butane (C_4), and an alkane series up to C_{34}, which includes various isomers and unsaturated isomers. Some of the wood derived compounds were: carbon dioxide, 3-furancarboxaldehyde (2.33 min), 5-methyl-2-furancarboxaldehyde (5.17 min), phenol (6.30 min), methylhydroquinone (7.91 min), 2-methyl-phenol (8.22 min), guaiacol (8.71 min), 4-hydroxy-3-methylbenzaldehyde (10.43 min), 3,4-dimethylphenol (10.76 min), 2,5-dimethylphenol (11.29 min), 4-methylguaiacol (11.65 min), hydroquinone (12.32 min), 3-methyl-4-ethylphenol (12.92 min), 4-vinylphenol (12.67 min), 2-(1-methylethyl)-phenol (13.15 min), 4-methylcatechol (13.84 min), 4-ethylguaiacol (14.00 min), 4-allylphenol (14.50 min), 4-vinylguaiacol (14.79 min), 2-methoxy-4(1-propenyl-phenol (15.98 min), isovanillin (16.50 min), 5-methylguaiacol (17.00 min), eugenol (17.21 min), 2-allyl-4-methyl-phenol (17.62), 4-propylguaiacol (18.03 min), isoeugenol (18.20 min), acetoguaiacone (18.69 min), methyl-homovanillate (19.76 min), and guaiacylacetone (20.77 min) [1,16,17].

Quantitative analysis of the chromatograms obtained from Py-GC-MS was used to calculate the wood content from the weathered WPC. The result revealed that there was a decrease in wood content at the WPC surface during xenon, UV2000 and outside weathering as shown in Figure 5. Conversely, the plastic content at the surface increased during WPC weathering. It was noted that the wood content at the surface decreased significantly even after 400 h of xenon and UV2000 exposure. These results support the observations made on wood lignin from FTIR spectra.

Statistical analysis was conducted to test the differences between the effect of xenon and UV2000 as well as the effect of exposure time within each of accelerated weathering regimes (xenon and UV2000) on the wood content using one-way analysis of variance (ANOVA, $\alpha = 0.05$). The results of t-test conducted showed that there is significant difference between the xenon and UV2000 weathered WPC. The wood content of the xenon weathered WPC was significantly lower than that of UV2000. This indicates that more wood was lost from weathered surface in xenon than in UV2000. Also, the wood content of the unweathered WPC (in both xenon and UV2000) was significantly higher than the weathered WPC. However, xenon weathered WPC show that there is no significant difference in the wood content from 400 to 1600 h of exposure but it was significantly lower at 2000 h compared to UV2000 weathering regime (Figure 5a). Wood content in the outside exposed WPC also decreased with longer exposure time (Figure 5b).

Relationship between color and wood chemical changes of weathered WPC

The results of the chemical and color changes in this study were employed in building the relationships that might exist between chemical and color changes upon WPC weathering using multiple regression analysis. Several equations were generated which show the relationships that exist between chemical and color changes but only those that have high coefficient of determination (R^2) at 0.05 level of probability were selected and presented in Table 2. The combination of wood content, carbonyl index and/vinyl index as well as the exposure time are good factors that could be used to predict the color change and surface lightness of WPC when subjected to varying environmental conditions. Concisely, the wood content, vinyl index, carbonyl index and exposure time seem to be quite useful for the prediction of both color change and surface lightness of xenon weathered HDPE/pine composites. The R^2 values of the models were not only dependent on, but these equations were validated and the results of the t-test between the laboratory data and the predicted values generated were statistically not significant at 0.05 level of test. Therefore, decrease in wood content relative to lignin, increase in vinyl groups and surface oxidation as well as exposure time resulted in increased color change and surface lightness. It can be deduced from these relationships that if wood can me modified using appropriate methods and chemical, wood lignin degradation and surface oxidation could be minimized. This in turn will lower color change and surface lightness of WPC production.

Table 2. Relationships between chemical and color changes of xenon weathered WPC.

Equations	R	R^2	Lab data vs predicted
Lightness = 3.3Wood – 3.4VI + 25.4lnt – 1174.3	0.99	0.98	ns
Lightness = 1.2Wood – 1.7CI + 18.4lnt – 100.9	0.95	0.91	ns
Color change = 1.5Wood – 4.5CI + 17.1lnt – 68.5	0.95	0.91	ns
Color change = 1.2VI – 2.0CI + 12.5lnt – 48.4	0.89	0.79	ns

Where CI is carbonyl index, VI is vinyl index and lnt is natural logarithm of time (h).

Conclusions

In this study, the effects of WPC weathering on the color, UV absorption and chemical characterization were examined. Weathering of WPC resulted in a definite color change, mainly surface lightening, and this occurred through continued exposure. The generation and increment of new chromophoric groups such as carboxylic acids and vinyl groups, and the loss of lignin at the weathered WPC surface with increased exposure time were observed by infrared studies and also confirmed by UV-Vis spectroscopy. Py-GC-MS was employed to determine the surface composition (wood/plastic) of weathered WPC. It was shown by Py-GC-MS results that the wood content decreased upon WPC weathering. Also, different weathering regimes had different weathering pattern. More importantly, the connectivity between chemical and color change is established.

Acknowledgements

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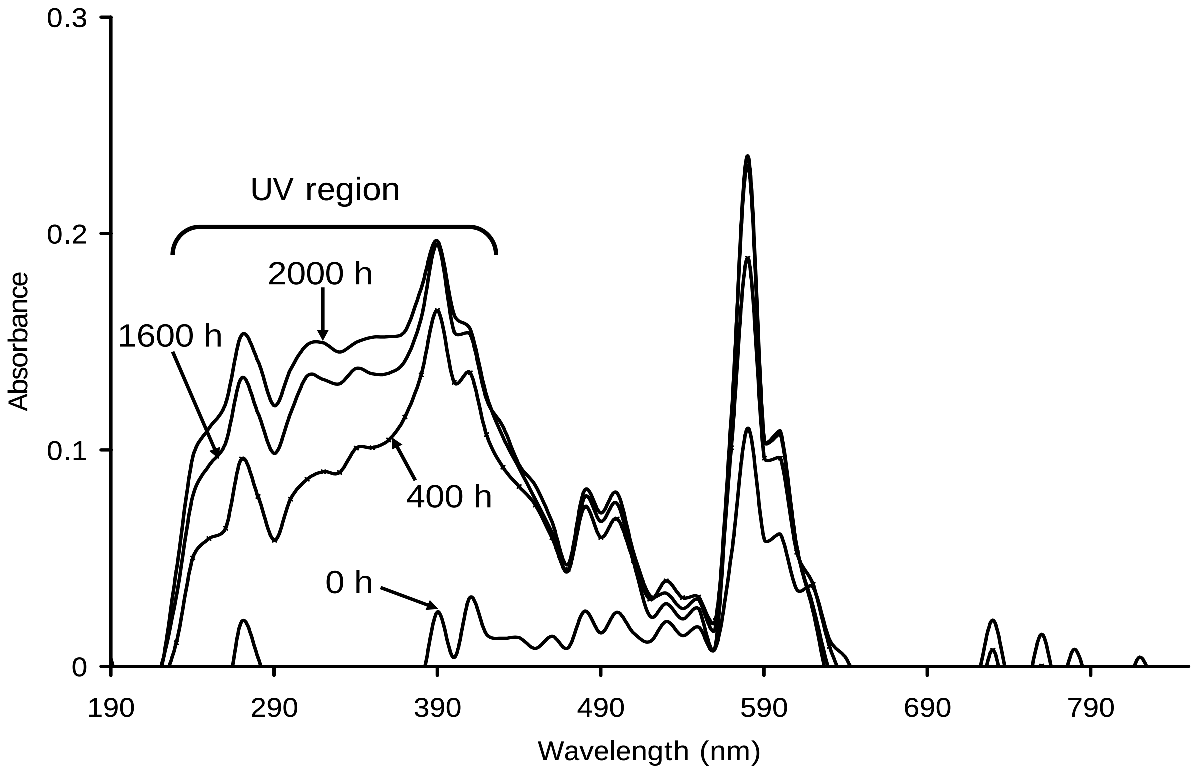
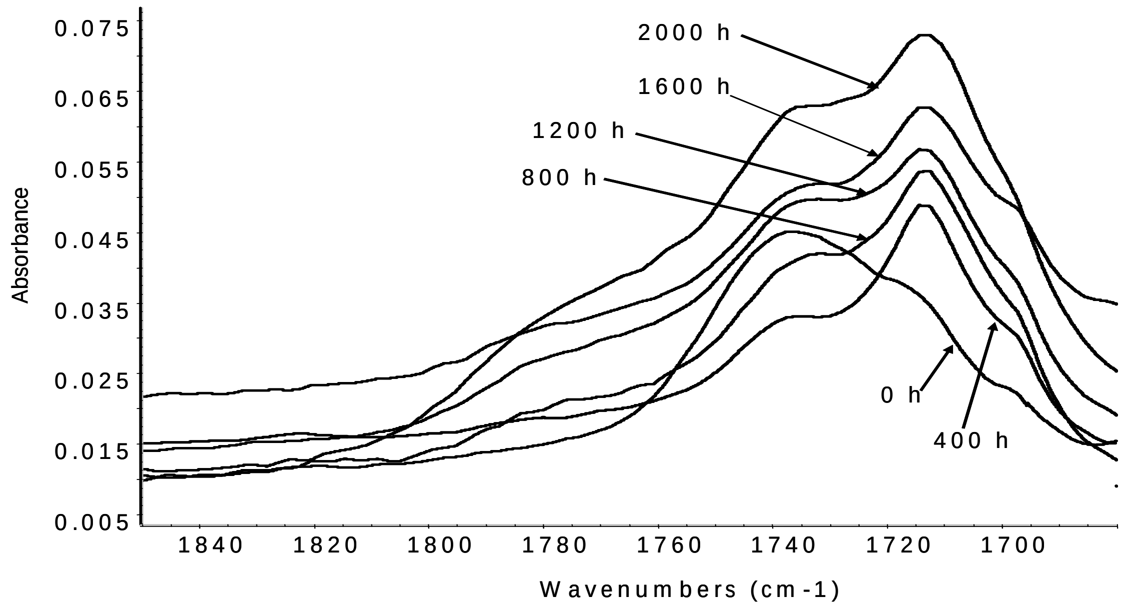


Figure 1. Ultraviolet absorption level by HDPE/pine composites upon xenon weathering

(a)



(b)

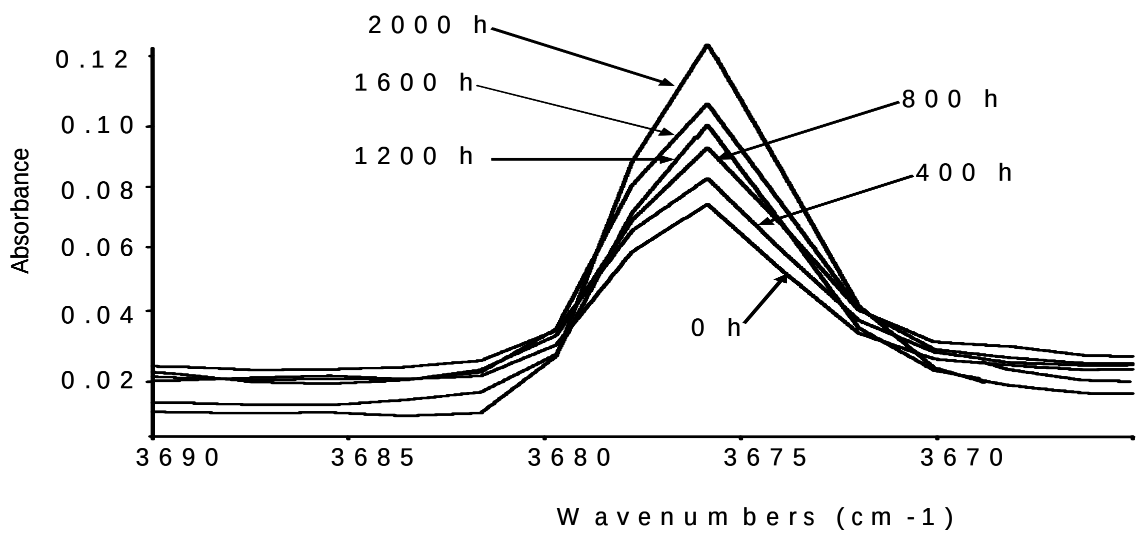
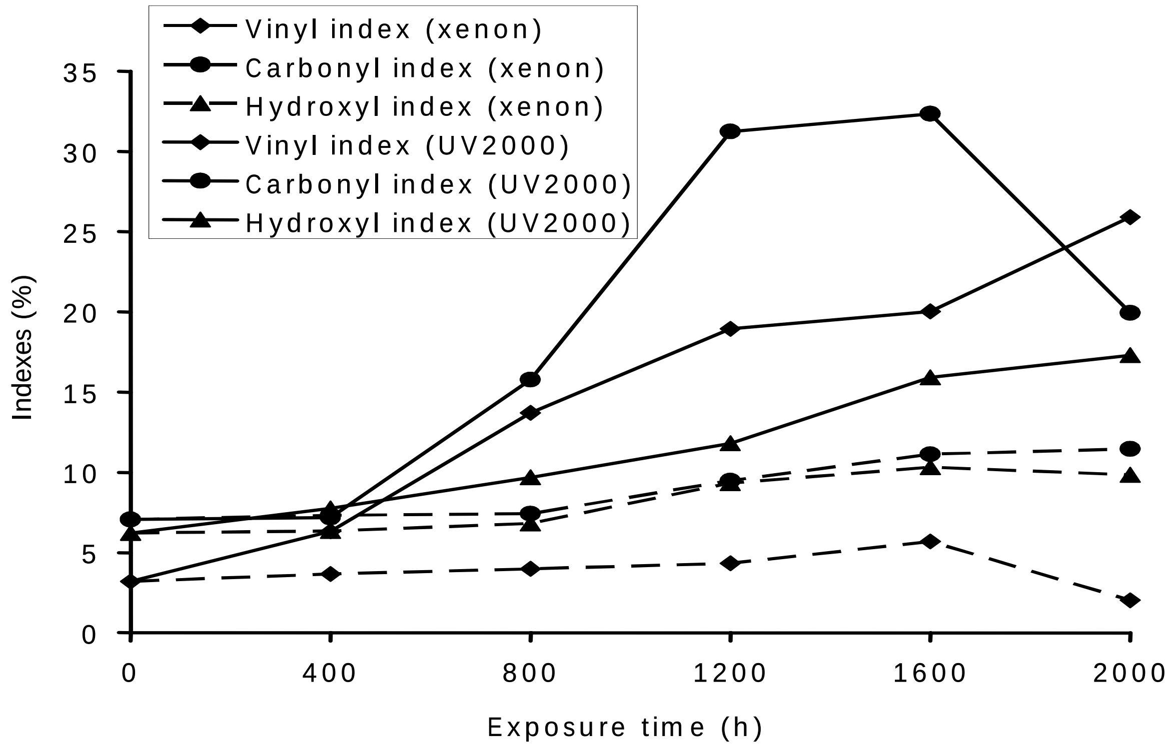


Figure 2. Infrared spectra of HDPE/pine composites exposed to xenon weathering regime: (a) carbonyl group region, (b) hydroxyl group region from talc.

(a)



(b)

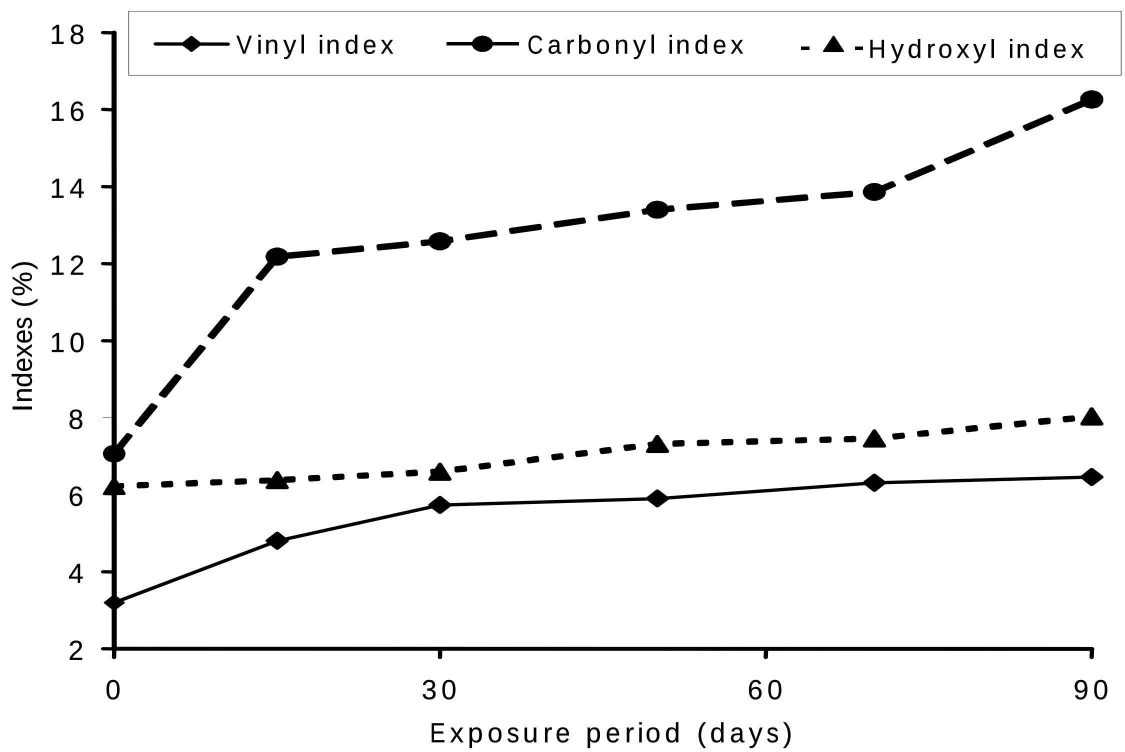


Figure 3. Functional groups changes upon (a) accelerated and (b) outdoor weathering of HDPE/pine composites.

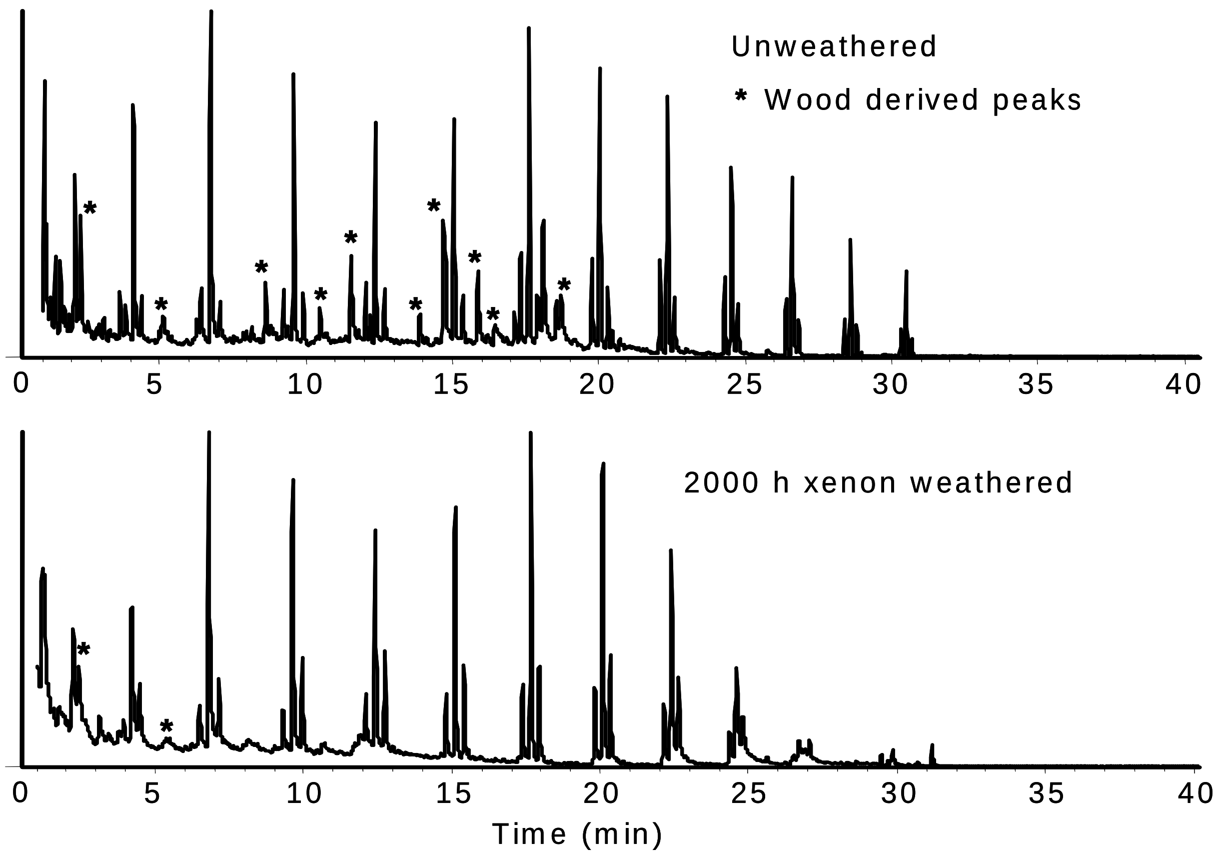


Figure 4. Chromatograms of (top) unweathered and (bottom) weathered HDPE/pine composites.

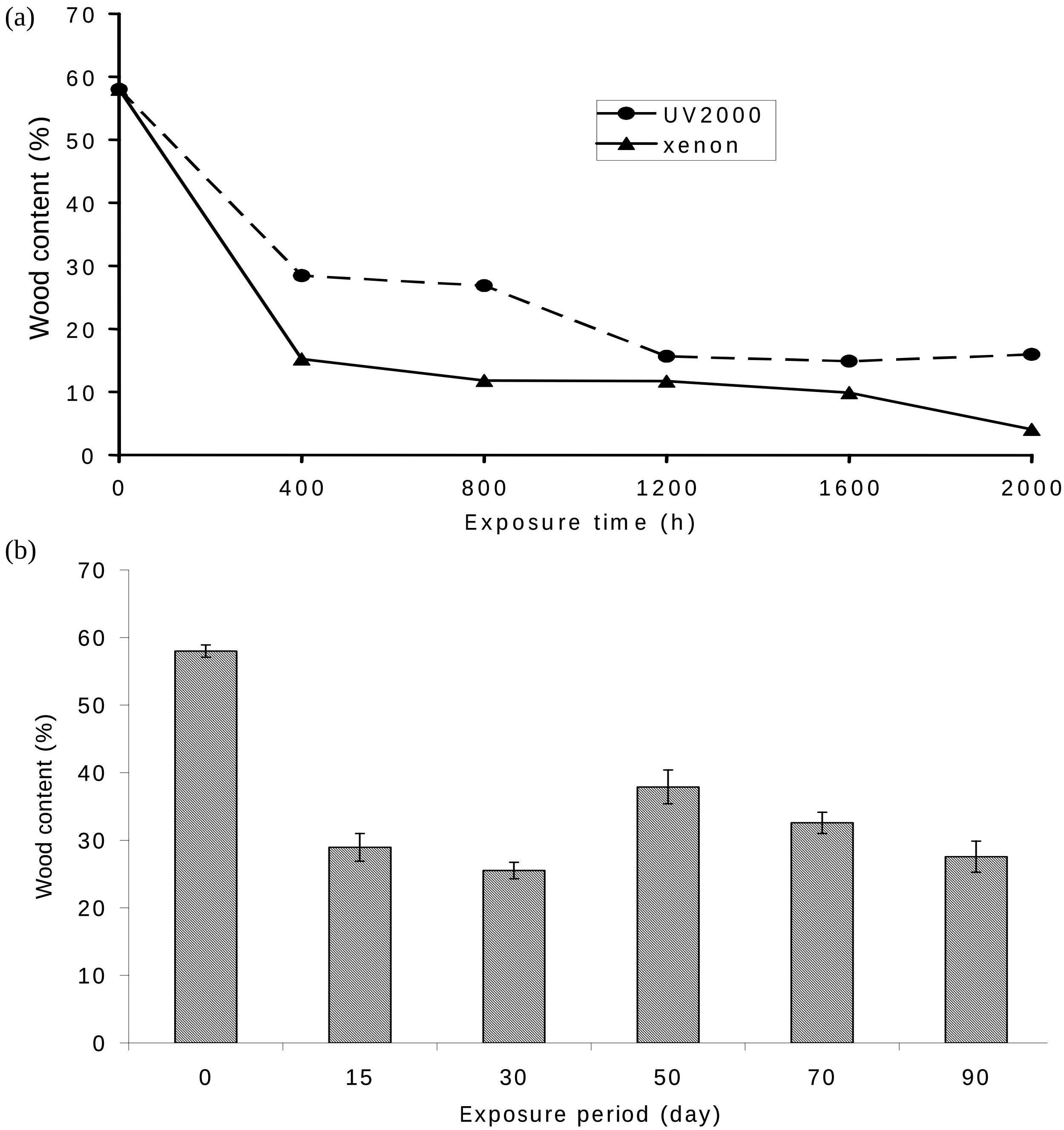


Figure 5. The effect of (a) accelerated weathering and (b) outside weathering on wood content of HDPE/pine composites.

Part B:
Effect of Wood Species on the Weathering of WPC

James S. Fabiyi, Armando G. McDonald, Karl Englund and Michael P.Wolcott

Summary

The effects of weathering on the color, UV absorption and surface oxidation of WPC made from the five different wood species were examined. UV-VIS colorimetry and spectroscopy as well as Fourier transform infrared (FTIR) were the analytical tools used. The general trend of WPC weathering shows that discoloration, chromophores generation and surface oxidation increased upon longer exposure. UV-Vis light spectroscopy was used to measure the UV absorption so as to investigate the level of chromophoric elements present during weathering of HDPE based WPC from the five different wood species. Weathering of WPC resulted in a definite increase in the UV absorbance through 2000 hours exposure suggesting formation of more chromophoric elements with longer exposure time. WPC degradation by surface oxidation (carbonyl index) and unsaturation (vinyl index) were monitored by FTIR-ATR spectroscopy and these generally increased with increased exposure time, however, the increase in vinyl index was not significant. From these results, especially the discoloration data, hybrid poplar and ponderosa pine are preferred wood species for WPC production for applications where color stability is of high priority.

Introduction

Exposure of wood plastic composites to varying environmental conditions such as UV radiation from sunlight, changing atmospheric moisture and temperature results in chemical modification to the structure of the material components of WPC and in consequent to its color change [1]. Also, the color fades and properties change of WPC during weathering is becoming a great concern both to the manufacturers and consumers. It must be noted that several works have been conducted on weathering and durability issues of WPC [1-4]. Preliminary investigations have shown that weathering of WPC resulted in change of surface chemical and color properties [2]. Lignin content in WPC was shown to be greatly affected by weathering and this might have contributed significantly to color change (3rd ONR report, July 2005). This finding is supported from the literature that lignin is a good ultraviolet (UV) radiation absorber and therefore, the energy, which is transferred in the range of 200-400 nm, initiates degradation processes [5]. Therefore, lignin is primarily responsible for the absorption of UV radiation by wood and that lignin shows early effects of degradation caused by weathering [6]. Based on these findings, the use of wood species with low lignin content may likely reduce the color change of exposed WPC made from such wood. However, there is little or inadequate information on the effects of wood species on the weathering of WPC. Therefore, this work aimed at screening wood species so as to come up with a WPC product with improved weathering performance.

Indeed, there is no new property examined in this study but two analytical tools which have been proven to be fast and precise were employed to screen for the best wood species (2nd to 4th ONR report, 2005). These two analytical tools are UV-Vis spectroscopy and Fourier Infrared

Transform spectroscopy for monitoring color change, chromophores generation and surface oxidation, respectively.

Materials and Methods

Materials. The polymer matrix used in this study was high-density polyethylene (HDPE, 40% weight basis) together with five different wood species (60 mesh, 60% weight basis) reinforcement. No additives were used. Details of extrusion is similar to the extrusion process reported in January 2005 Progress Report for the Durable Wood Composites for Naval Low-Rise Buildings project. The extruded profiles were surface planed to produce the specimens for both accelerated and natural weathering tests. Samples for accelerated (xenon-arc) weathering tests were cut into 0.2” x 1.5” x 4” specimens.

Wood species selection. The five wood species used were selected based on their lignin content, dimensional stability, natural durability, and mechanical properties. Softwood species that were used for the study include: (i) **Douglas-fir** because of its moderate lignin content, low dimensional shrinkage, moderate durability, and moderate mechanical properties; (ii) **ponderosa pine** because of its moderate lignin content, low dimensional shrinkage, poor durability and low mechanical properties (Table 1) [7-8]. Three hardwood species evaluated covers a range of properties: (i) **black locust** based on its high lignin content, moderate dimensional shrinkage, excellent durability and high mechanical properties; (ii) **white oak** because of its high lignin content, moderate dimensional shrinkage, good durability performance and high mechanical properties; (iii) **hybrid poplar** because of its low lignin content, moderate dimensional shrinkage, poor durability and low mechanical properties.

Table 1. Strength properties (at 12% moisture content) of some commercially important woods grown in the United States.

Wood species	S.G. [7]	Lignin content (%)[8]	Volumetric shrinkage (%)[7]	Hardness (KN)[7]	MOE (GPa) [7]	MOR (MPa) [7]	Durability [7]	Color
				Hardwood				
Maple (sugar)	0.63	22	14.7	6.4	12.6	109	Slightly	
Black locust	**0.69**		**10.2**	**7.6**	**14.1**	**134**	**Excellent**	Dark
White oak	**0.68**	**27**	**12.7**	**6.0**	**12.3**	**105**	**Excellent**	
Black oak	0.61	24	15.1	5.4	11.3	96	-	
Birch sweet	0.65	21	15.6	6.5	15.0	117	Slightly	
Hickory, water	0.62	-	-	-	13.9	123	Slightly	
Black walnut	0.55	-	12.8	4.5	11.6	101	Excellent	
Yellow poplar	0.42	20	12.7	2.4	10.9	70	Slightly	Light
Hybrid poplar	**0.32**	**19**	**7.0**	**-**	**4.1-6.0**	**45-55**	**Poor**	Light
				Softwood				
Douglas fir	**0.48**	**26**	**10.4**	**2.7**	**12.3**	**90**	**-**	Medium
Western larch	0.52	27	14.0	3.7	12.9	90	Moderately	
Longleaf pine	0.59	30	12.2	3.9	13.7	100	Moderately	
Loblolly pine	0.51	27	12.3	3.1	12.3	88	Slightly	
Ponderosa pine	**0.40**	**26**	**9.7**	**2.0**	**8.9**	**65**	**Slightly**	Light
Red spruce	0.40	28	11.8	2.2	11.1	74	Slightly	

Accelerated Weathering of WPC. Accelerated weathering tests were conducted in a xenon-arc weatherometer (Q-Sun). The samples were subjected to an accelerated weathering procedure by exposure to 340-nm xenon lamps (UV-A region) in the accelerated weathering tester. The average irradiance was 0.72 W/m^2 at 340-nm wavelength with a chamber temperature of approximately 70^oC with water spray. Tests were performed according to the ASTM D 6662 [9] standards. The sample condition was assessed at 0, 50, 100, 150, 200, 400, 800, 1200, 1600 and 2000 hours.

UV-VIS spectroscopy and color measurement. Diffuse UV-VIS reflectance spectra on weathered samples was recorded using a StellarNet EPP2000C UV-VIS spectrometer (190-850 nm) with a deuterium light source (SL3, StellarNet) with a diffuse reflectance fiber optic probe. From the spectra, chromophores (e.g. unsaturated groups) were characterized. The surface color of weathered WPC specimens (at 3 locations) was determined in accordance with the ASTM 2244 procedures [10] using a StellarNet EPP2000C UV-VIS spectrometer and tungsten-krypton light source (SL1, StellarNet) and software with a diffuse reflectance fiber optic probe. The spectrometer is calibrated with a RS50 white Halogen standard (>97% reflectance). The spectrometer software transforms spectral data into CIELAB color coordinates (L*, a* and b*). Lightness (*L*) and chromaticity coordinates (*a* and *b*) were measured for five replicate samples from same WPC types, and the color change (ΔE_{ab}) was determined. L*, a*, and b* color coordinates of each sample, before and after exposure to natural and accelerated weathering testing, were calculated on the basis of a D65 light source as established by CIE [11].

Fourier Infrared Transform Spectroscopy. Surface oxidation and vinyl index were examined using FTIR spectrometer (ThermoNicolet Avatar 370) in the attenuated total reflectance (ATR, SmartPerformer, ZnSe crystal) mode and mathematically ATR and baseline corrected prior to comparing the changes in the carbonyl and vinyl regions of WPC (4 sampling points). From the weathered and unweathered samples, 50-100 µm slices were cut using a razor blade and vacuum dried. From FTIR spectra, special interest was on the bands at 908 and 1715 cm^{-1}, which correspond to absorption from the presence of vinyl (C=C) and carbonyl (C=O), respectively. The band (2916 cm^{-1}, C-H stretch, assigned to HDPE) that was less sensitive to weathering effect will be taken as reference peak. Carbonyl groups account for most of the photo-oxidation products of polymer materials; therefore the carbonyl index was determined as the ratio of absorbance of the band (1715 cm^{-1}) and reference band [12]. Estimation of unsaturation was done using vinyl index as the ratio of absorbance of the band (908 cm^{-1}) and reference band (2916cm^{-1}) [12].

Results and Discussion

Color changes and chromophores formation of weathered WPC

Surface lightness (ΔL^*) and color change (ΔE_{ab}) of weathered HDPE based WPC made from five different wood species are illustrated in Figure 1. WPC surface discoloration observed in this study provided the evidence of photodegradation. Surface lightness and color change increased upon weathering until 1200 h. The results are consistent with other weathering studies [11-13]. It was observed that HDPE/poplar composites had the least surface lightness and discoloration. The discoloration of the WPC from the five different wood species rank as follow:

Hybrid poplar < Ponderosa pine < White oak < Douglas fir < Black locust, however, the surface lightness ranked slightly different from that of discoloration pattern (Hybrid poplar < Ponderosa pine < Douglas fir < White oak < Black locust. Based on this study, hybrid poplar and ponderosa pine seemed to be the preferred wood species for the production of WPC with improved color performance.

Ultra-violet (UV) absorbance spectra of the xenon weathered WPC was used to deduce the chromophoric elements (or electronic structure of molecules) generation during weathering, hence UV-VIS reflectance spectroscopy was employed to measure the UV absorbance spectra of the WPC. Figure 2 showed the UV irradiance absorbance of xenon weathered WPC increased with longer exposed time. The absorbance between 190 and 400 nm is associated with molecules containing π–electron systems, i.e. presence of unsaturated vinyl groups. Comparing this observation to surface lightness and discoloration (Figures 1 a & b) as well as carbonyl and vinyl indexes (Figures 3c, 4a & b), the results revealed that chromophores are generated or increased upon weathering; thereby confirming increase in polymer chain scission.

Surface chemistry

A series of IR spectra for xenon accelerated weathered WPC were recorded. The spectra revealed that there are bands that are formed or disappeared while some increased or decreased on WPC surface upon longer exposure. The OH group at 1015-1030 (free bond) and 3050-3600 (hydrogen bond) cm-1 regions are assigned to wood hemicellulose and wood chemicals (combination of cellulose, hemicellulose and lignin). These bands decreased upon weathering as evident from all the five wood species based WPC (Figure 3a). The band at 1508-1512 and 1595 cm^{-1} due to ether functional group from wood lignin disappeared upon longer exposure to any of the weathering regimes (Figure 3b). This indicates that lignin degradation occurred on the weathered WPC surface. More importantly, the bands at 908 ± 10 and 1650-1800 cm-1 are assigned to the carbonyl functional groups. This carbonyl region corresponds to: conjugated ketones (1700-1675 cm^{-1}), carboxylic acids (1725-1710 cm^{-1}), esters and aldehydes (1735-1720 cm^{-1}) [14]. The increased in carbonyl groups bands (Figure 3c) provided evidence that surface oxidation has taken place and in turn, it is an evident of photodegradation with extended exposure time. It also means that the material is vulnerable to further degradation because these carbonyl groups are photolabile [15]. The extent of WPC oxidation was determined by its total carbonyl functionality (908 ± 10 cm-1) and quantified by its carbonyl index (CI). The CI for the xenon accelerated weathered WPC increased from 2 to 5, 3 to 6, 3 to 10, 2 to 8, and 2 to 9 % for Douglas fir, Black locust, White oak, Ponderosa pine and Hybrid poplar respectively, as a function of exposure time (Figure 4a).

Vinyl groups observed in WPC are assumed to be due to the HDPE matrix as evident in the aliphatic band at 2915-2850 cm-1. The vinyl functional groups in this case occurred because of the chain scission (breakage in the long aliphatic chain) of the HDPE content. The total absorbance of bands between 908 ± 10 cm-1 was used to quantify the degree of unsaturated (formation of double bonds) by vinyl index (VI). For the xenon accelerated weathered samples, the VI show no significant increase (Figure 4b). The slight increase in VI can be explained since the wood is primarily attacked and washed away with water runoff thus increasing in HDPE content at the surface.

Conclusions

In this study, the effects of weathering on the color, UV absorption and surface oxidation of WPC made from the five different wood species were examined. The general trend of WPC weathering shows that discoloration, chromophores generation and surface oxidation increased upon longer exposure. Also, the unsaturation (C=C functional groups known as vinyl groups) slightly increased upon weathering indicating chain scission due to weathering. UV-Vis light spectroscopy was used to measure the UV absorption so as to investigate the level of chromophoric elements present during weathering of HDPE based WPC from the five different wood species. Weathering of WPC resulted in a definite increase in the UV absorbance through 2000 hours exposure suggesting formation of more chromophoric elements with longer exposure time. WPC degradation by surface oxidation (carbonyl index) and unsaturation (vinyl index) were monitored by FTIR-ATR spectroscopy and these generally increased with increased exposure time, however, the increase in vinyl index was not significant. From these results, especially the discoloration data, hybrid poplar and ponderosa pine are preferred wood species for WPC production for applications where color stability is of high priority.

Acknowledgements

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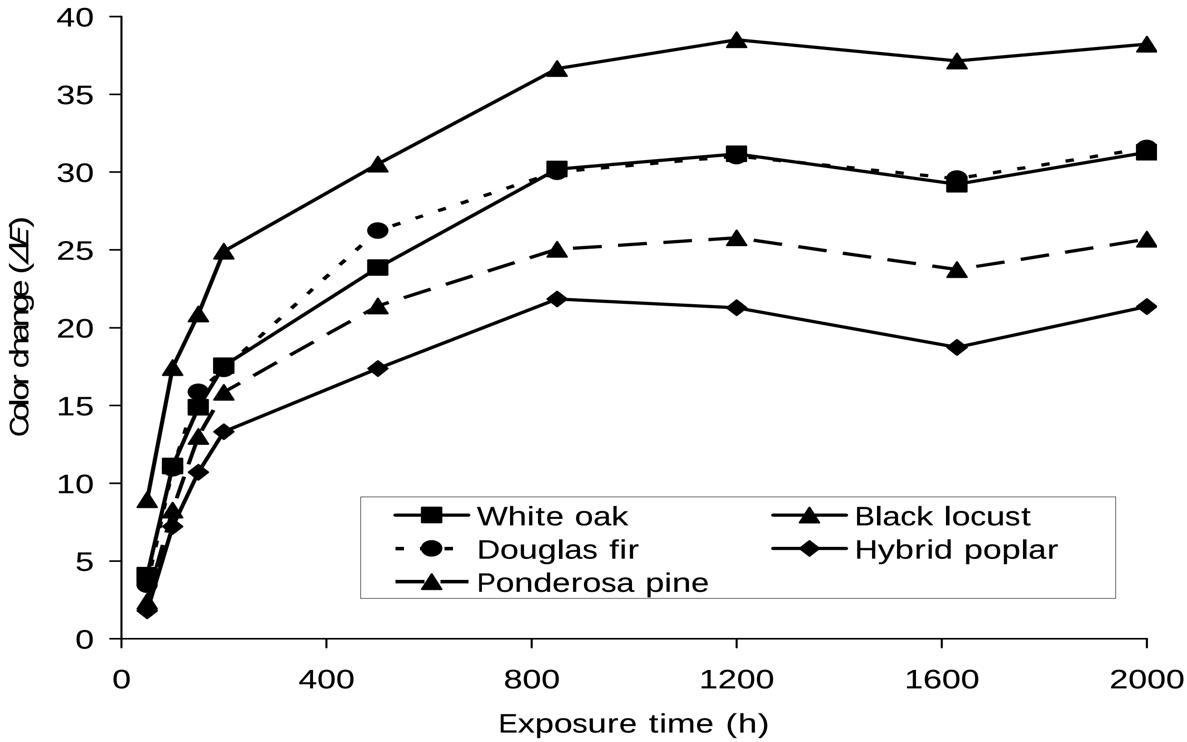
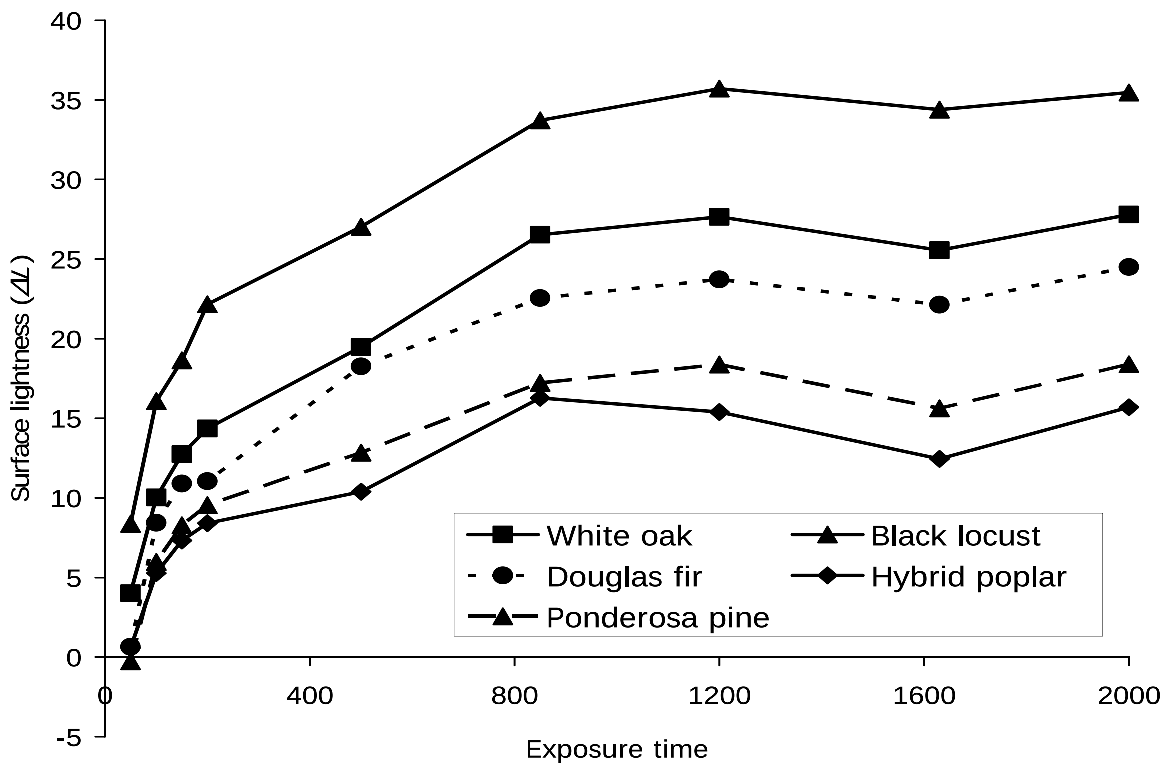
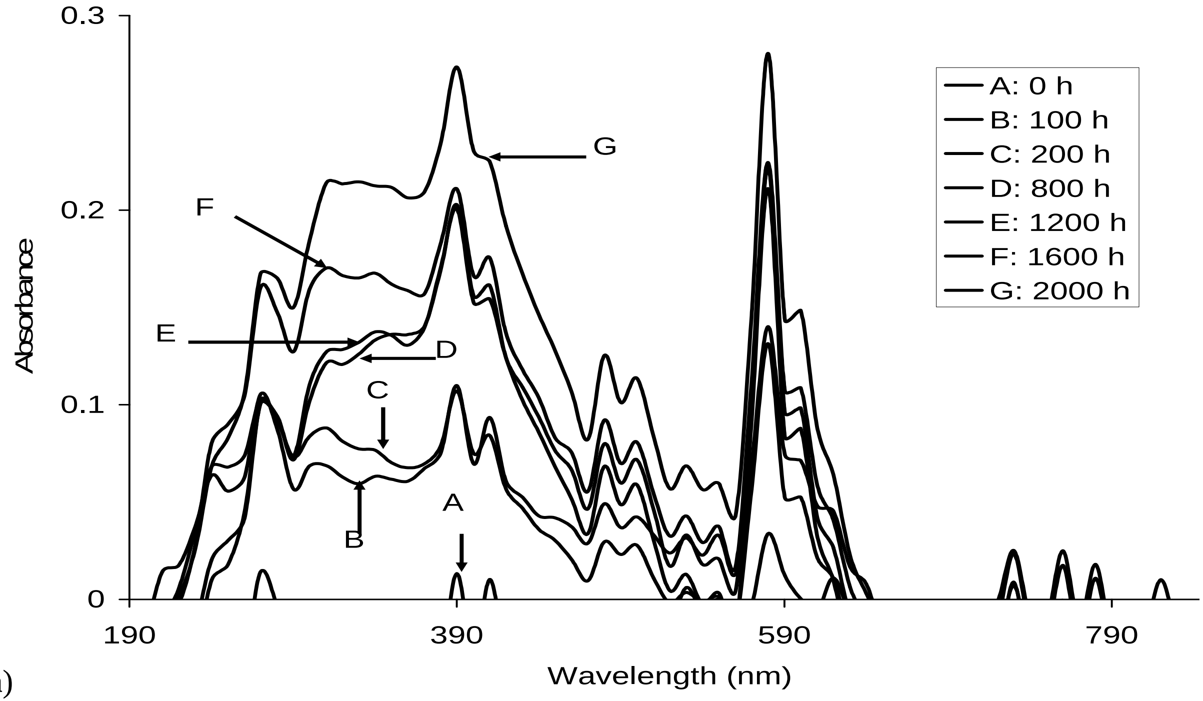


(**a**)



(**b**)

Figure 1. (a) Discoloration and (b) surface lightness of wood plastic composites made from different wood species.



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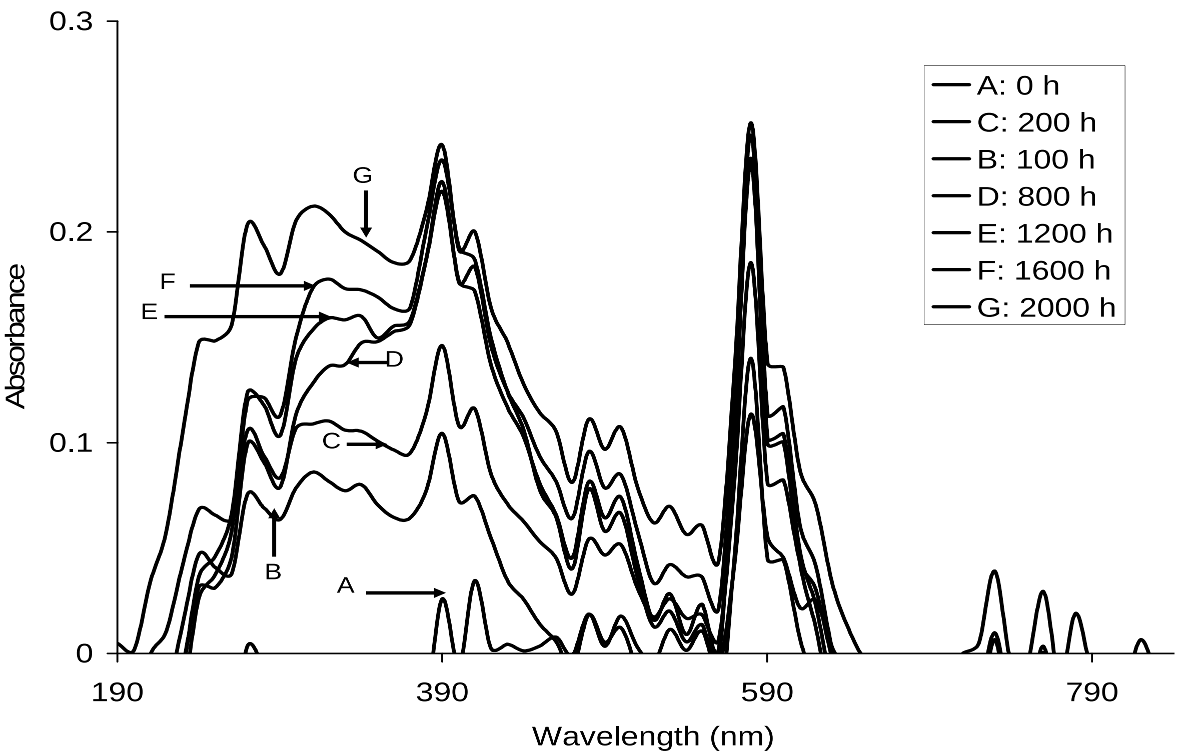


(**b**)

Figure 2. Effect of weathering on the UV-VIS absorption spectra of HDPE based WPC made from (a) black locust and (b) hybrid poplar.

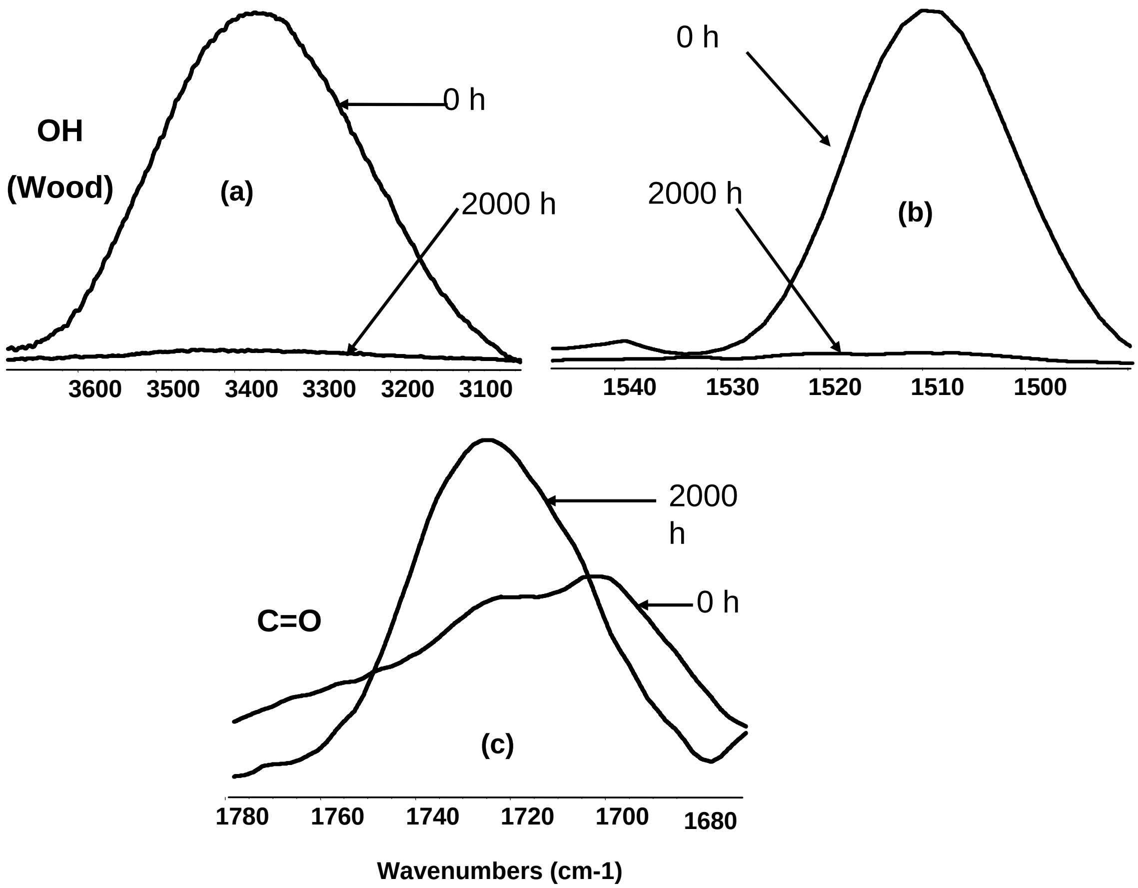
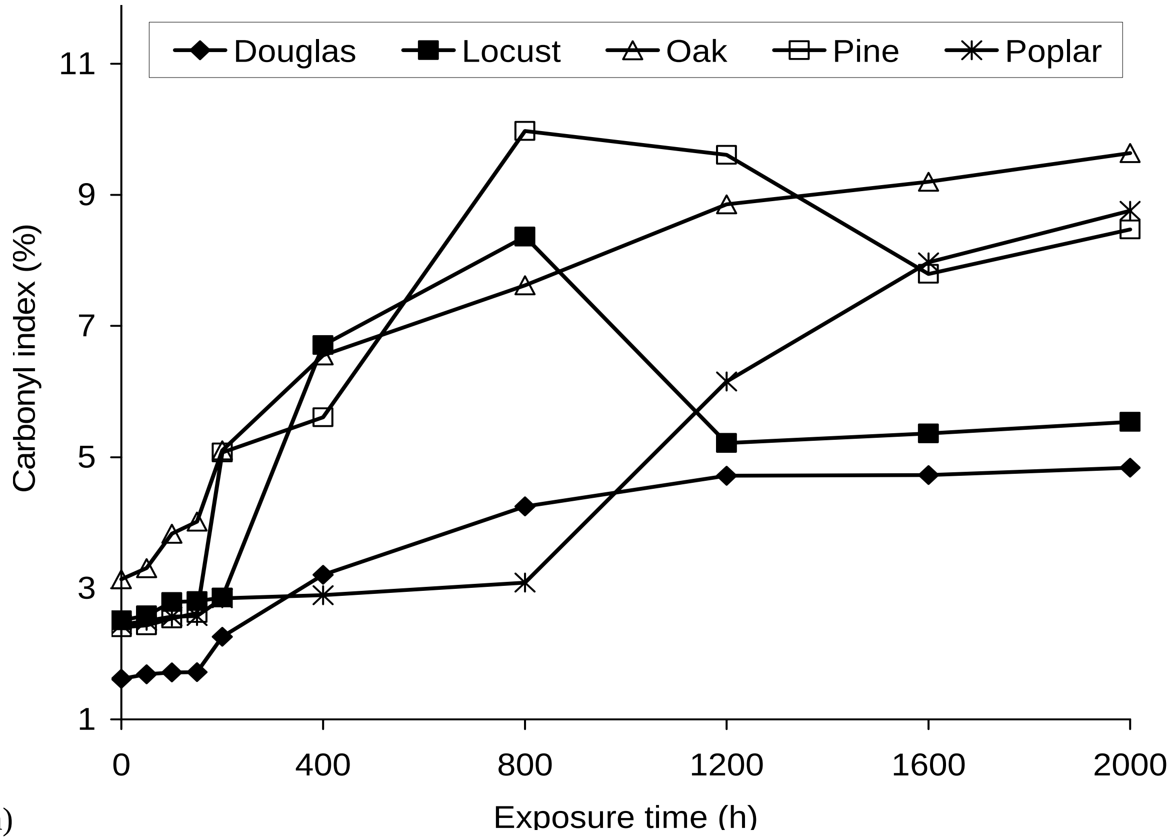
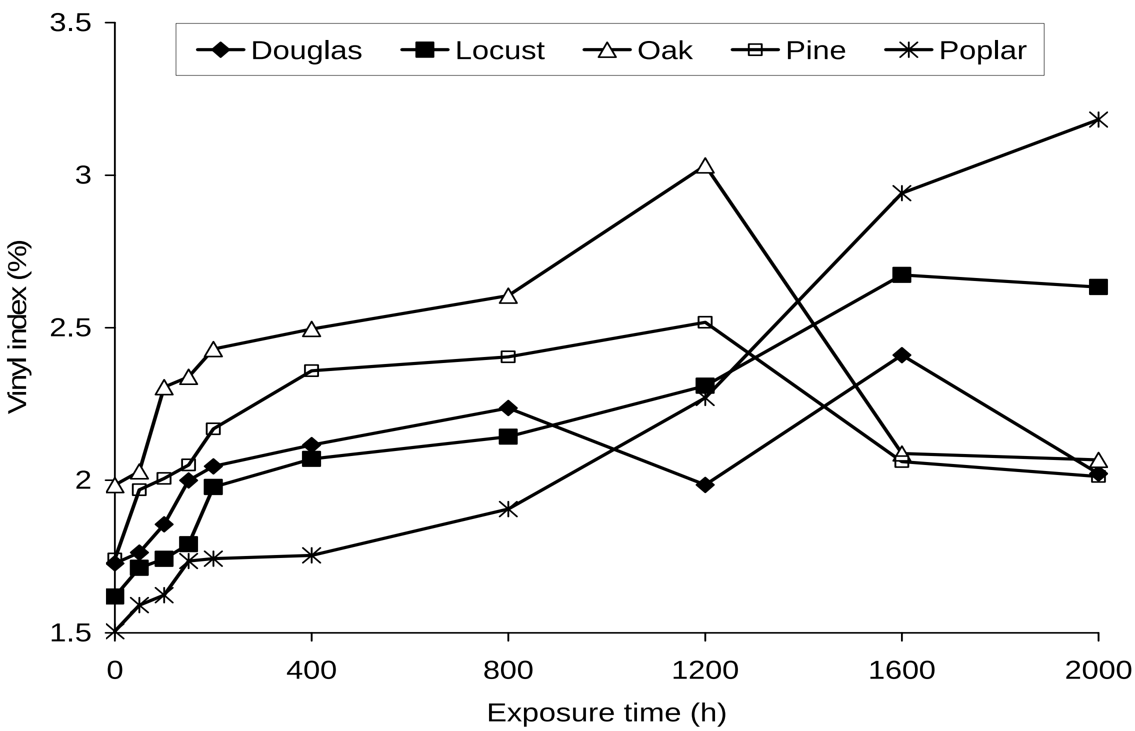


Figure 3. Effects of weathering on (a) hydroxyl (OH) group, (b) assigned lignin peak and (c) carbonyl (C=O) group, of WPC made from hybrid poplar.



(a)



(b)

Figure 4. Effect of xenon accelerated weathering on the (a) carbonyl and (b) vinyl groups of HDPE based WPC from five different wood species.

Durable Wood Composites for Naval Low-Rise Buildings

Weathering Effects on Fatigue Behavior of Wood Flour Filled High-Density Polyethylene Composites

Siding and Trim Components

Task S5 – Siding and trim components with improved weathering performance

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Abstract

The influences of accelerated weathering exposure on the fatigue life were investigated and a cumulative damage model is verified for predicting the fatigue life of wood flour-high density polyethylene composites. The model incorporates applied maximum stress, stress amplitude, accelerated weathering exposure time, residual modulus, and material constants as parameters.

Small coupon samples of wood flour-high density polyethylene composites were tested in flexural fatigue and the model is verified with experimental data. Applied stress ratio-life cycle (*S-N*) data was collected to generate stress ratio-fatigue life plot at five levels of applied maximum flexural stress between 70 and 90% at 10-Hz in each of 0 and 2,000-hrs ultraviolet (UV) light exposure time. Both the residual modulus at predetermined loading cycles and the number of cycles at which the samples fail are measured.

Fatigue life of weathered sample was shorter than that of unweathered sample due to the chemical decomposition during accelerated weathering. The results show that the loss in residual flexural modulus after UV exposure is slightly increased than that without UV exposure.

Damage model was verified using experimental data to describe damage growth in terms of material constants, stress ratio and accelerated weathering exposure time. The fatigue damage model agrees well with the intermittent static test data.

Introduction

The lignocellulosic material (including wood and other natural resources) filled thermoplastic polymer composites have been widely developed and used as house wares, car interior such as dashboard and various building materials (Lee et al. 2004; Yang et al. 2004, 2005, 2006, 2007). Natural filler reinforced polymeric composites will be able to combine good mechanical properties such as low specific mass and offer an alternative material to glass-fiber reinforced polymeric composites in some technical applications (Gassan 2002). Among the thermoplastic polymers, polyolefin have several good properties such as excellent chemical resistance, good mechanical properties and low cost. It might be able to combine the favorable performance and low cost attributes of both lignocellulosic materials and thermoplastic polymers, so that such lignocellulosic material reinforced polyolefin composites can be as an alternative to preservative-treated timber in both residential and commercial applications. In many transportation and pedestrian structures, repeated loading causes failure of the material, so that there is an imminent need to develop mathematical analysis and methodology for assessing the safety and reliability of using polymeric composites in these applications. One of the most important issues in regard to using polymeric composites in such structural applications is their fatigue reliability in different environmental and loading conditions. The fatigue behavior of composite materials has been studied to address problems resulting from their exposure to long term engineering service conditions (Kazanci et al. 2002). Typically, matrix cracking and delamination occur early in the life, while filler-matrix debonds initiate during the beginning of the life and accumulate rapidly towards the end, leading to final failure (Gassan et al. 2003). Fatigue damages in polymeric composites for non-structural applications have been widely investigated (Reifsnider 1991; Talreja 1987; Jang 1994; Martin 1995). However, there is little quantitative research on the

effects of civil engineering environments, namely, ultraviolet (UV) light and loading on the fatigue of polymeric composites.

The main objectives of this research are to evaluate fatigue properties of the composite using damage assessment, compare actual complex MOE and static modulus at a certain number of cycles, and to evaluate effect of accelerated weathering on damage growth during the fatigue life cycle. Small coupon samples of wood flour-high density polyethylene composites were tested in flexural fatigue to evaluate the influences of ultraviolet light exposure time and stress ratio on the fatigue life. The unexpected thermal failure caused by internal heating can occur during the fatigue life cycle in the full-scale deck board, therefore we selected small sized coupon to prevent internal heating.

This research presents the experimental verification of a cumulative fatigue damage model subjected to flexural loading at five levels of maximum applied stress in each of two UV light exposure time. The model can be used to predict the fatigue life of particle-reinforced polymeric composites under an applied load and to estimate the residual flexural modulus after predetermined number of loading cycles. Applied stress ratio-life cycle (*S*-*N*) data were collected to generate stress ratio-fatigue life plot between 70 and 90% at 10-Hz. Cumulative damage model was verified using experimental data to describe damage growth in terms of material constants, stress ratio and accelerated weathering exposure time.

Objectives

The research presented herein was conducted with the objective of advancing the acceptance and knowledge of fatigue properties of wood flour reinforced HDPE composite. The specific goals were to:

1) Evaluate fatigue properties of wood flour/HDPE composite using damage assessment,
2) Modify general fatigue damage model to evaluate effects of accelerated weathering by ultra violet light on damage growth of the composite during the life cycle, and
3) Compare complex modulus of elasticity and static MOE at a certain number of cycles to calculate actual damage growth.

Materials and Methods

Flexural cyclic load tests were performed to assess the fatigue response of a WPC formulation with different *S* ratios ($\sigma_{max}/\sigma_{ult}$ ratio) and exposure time in the weathering meter. Commercially available 60-mesh pine wood flour was obtained and dried in a steam tube dryer to a moisture content of approximately 2%. The polymer matrixes that will be used in this study is HDPE (Equistar petrothene, LB 0100-00, MFI = 0.3 g/10 min., and density = 0.950 g/mL) and pine wood flour (American Wood Fibers, 60 mesh) as reinforcement. Zinc stearate was used as lubricant. Talc was added as additional filler. Zinc stearate and ethylene bistearamide (EBS) wax were added as lubricants to aid in the extrusion process. **Table 1** summarizes the details of each of the components provided by the manufacturers.

Dry blending was carried out in a commercial drum mixer prior to extrusion. The materials were dry blended in powdered form using a 4-ft (1.2-m) drum mixer in a series of 55-lb (25-kg) batches. A 55-mm conical counter-rotating twin-screw extruder operating at 5 to 12 rpm was used to produce 0.375-in x 1.5-in rectangular section. The temperatures of the barrel and die ranged from 300-380°F and were held constant throughout the extrusion runs. Presently, only one formulation of each WPC type is used in this study. After the mixing, the dry blended compounds were fed into the extruder's barrel through hopper for processing. The extrusion quality was enhanced by the use of a stranding die (Laver, 1996). The extrudates were surface planed to produce the samples for both control sample and accelerated weathering tests. Samples were cut into 0.21-in (5.33-mm) in thickness, 1.5-in (38.10-mm) in width and 4-in (101.60-mm) in length. The samples were machined to size and environmentally conditioned at 70-degrees F (21.1° C) and 50-percent RH. Accelerated weathering test was conducted in a xenon-arc (Q-sun) weather-o-meter. WPC samples were subjected to an accelerated weathering procedure (average irradiance was 0.72 W/m^2 at 340 nm, chamber temperature of 70° C and water spray) according to the ASTM D 6662 standard for xenon-arc weather-o-meters. The test samples were analyzed for a total of 2,000-hrs.

Fatigue testing was performed in an environmentally conditioned room maintained at 70-degrees F (21.1° C) and 50-percent RH. Coupon flexural fatigue tests were carried out on samples with dimensions that were: 0.67-in. (17.02-mm) wide, 0.21-in. (5.33-mm) deep, and 4-in. (101.60-mm) long for an L/D ratio of 13.44 to get the data within a reasonable time. The applied spans were 2.82-in. (71.69-mm) long. A 1-kip load cell attached to a servo-hydraulic universal testing machine (MTS model 602.10A-01) was utilized for the application of the load and the data was acquired in real time by means of a computer. The modulus of rupture (MOR) values, obtained from the static tests, were used as a reference stress level in the determination of the applied maximum loads.

The fatigue tests consisted of applying controlled levels of cyclic stress using a servo-hydraulic, universal testing machine set to operate in load-control mode. Loads were applied to three replicate samples for each maximum stress level. The applied maximum stress levels ranged from approximately 70 to 90-percent of the ultimate static strength and the minimum stress levels were approximately 10-percent of each of the maximum stress levels. Namely, maximum stress to ultimate stress ratios (*S* ratios) of 0.70 to 0.90 and a minimum stress to maximum stress ratio (*R* value) of 0.1 were applied. The stresses applied in each test are reported in **Table 2**. During testing, each sample was loaded to the prescribed maximum/minimum stress levels and these loads were maintained until break occurred. A frequency of 10-Hz was used to obtain meaningful results within a reasonable time.

Residual modulus and partial damage were measured at a certain numbers of loading cycles under a given maximum load by intermittent static test to calculate damage growth. Fatigue loading was stopped and static flexural tests were performed right after beginning of each order of magnitude (10^3, 10^4, 10^5 *etc*.). Residual modulus can be calculated from the slope between 20 and 40% of ultimate stress in the stress-strain curve. When the applied stress reaches 40% of ultimate stress, static loading was stopped and fatigue loading restarted immediately to prevent load release of each samples.

Cumulative Damage Calculation

A model of the cumulative damage as a function of the number of loading cycles was suggested in a previous study (Tang et al., 2000). Matrix cracks occur early in the fatigue process and are due to the high concentration of stress. As the number of cracks increases, stress redistribution reduces the initiation of new cracks and the damage appears to grow at a constant rate as the cyclic loading continues. Interfacial debonding and breaking start and gradually increase at the point where damage occurs. The extent of interfacial debonding and breakage increases due to the continuing growth of the matrix cracks. As the breakage progresses and intensifies, the rate of interfacial debonding increases rapidly and the composite ultimately ruptures as shown in **Figure 1**.

Damage is the state variable which can measure the condition of the material such as matrix cracking, delamination and filler-matrix debonding. It is related to various loading such as fatigue, creep and load-duration. Damage can be measured from a change in residual modulus and the rate of damage propagation can be expressed the function of damage state. If the material has higher damage state, it causes more rapid damage propagation and finally, material ruptures quickly.

The general fatigue model may take the form

$$\frac{dD}{dN} = \frac{C_1}{D^{n1}} + \frac{C_2}{(1-D)^{n2}} \tag{1}$$

However, our experimental data and previous research (Tang et al., 2000) on the cumulative damage, D, as a function of the number of loading cycles, N, for the composite do not show any initial weakening of the material strength until the number of loading cycles exceeds 10^4 as shown in **Figure 2**. Further, the data on the initial damage do not reveal any evidence of abrupt growth. Instead, the data show smooth and gradual increases in the amount of damage as shown in **Figure 3**. This result is similar to that obtained in previous studies of fiber reinforced composites, which showed little degradation in the modulus (Tang et al., 2000; Kadi and Ellyin 1994). Therefore, for the composite material used in this research, C_1 is negligible in comparison with C_2. Consequently, the damage rate per loading cycle may be expressed as

$$\frac{dD}{dN} = \frac{C}{(1-D)^n} \tag{2}$$

Equation (2) may be rewritten as described in the fatigue behavior of wood flour filled polypropylene composites section

$$\frac{dD}{dN} = \hat{C}\frac{(\sigma_{max}\sigma_{amp})^m}{(1-D)^n} \tag{3}$$

where $\hat{C}$, m, and n = material constants

σ_{max} = maximum stress, σ_{min} = minimum stress

σ_{amp} = cyclic stress amplitude, equal to (σ_{max} - σ_{min}).

We can express the maximum stress and stress amplitude, normalized to the ultimate strength, σ_{ult}, and the minimum to maximum stress ratio, R, as follows:

$$\sigma_{max}\sigma_{amp} = S_{max}{}^{2}(1-R)\sigma_{ult}{}^{2}$$

Substituting σ_{max} and σ_{amp} into (3) and then simplifying, the equation becomes

$$\frac{dD}{dN} = C\frac{(S_{max}{}^{2}(1-R))^{m}}{(1-D)^{n}} \tag{4}$$

where $S_{max} \leq 1$ and $C = \hat{C}\,(\sigma_{ult})^{2m}$

Integrating (4) and substituting the initial condition (D = 0 when N = 0) we obtain

$$\frac{1}{n+1} - \frac{(1-D)^{n+1}}{n+1} = C(S_{max}{}^{2}(1-R))^{m}\,N \tag{5}$$

where $0 \leq D \leq 1$.

When the number of loading cycles approaches the maximum number of life cycles, N_f, D approaches 1. Under this condition, (5) becomes general fatigue model

$$\frac{1}{n+1} = C(S_{max}{}^{2}(1-R))^{m}\,N_{f} \tag{6}$$

This equation can also be simply expressed in log-log form as

$$\log S_{max} = a + b\log N_{f} \tag{7}$$

Determination of Material Constants

The constants m, n, and C in equations (5) and (6) can be obtained from the experimental data. By taking the logarithm on both sides of (6), we obtain:

$$-\log(n+1) = \log C + 2m\log S_{max} + m\log(1-R) + \log N_{f} \tag{8}$$

$$\log S_{max} = -\frac{1}{2m}\log((n+1)C(1-R)^m) - \frac{1}{2m}\log N_f \quad (9)$$

Therefore, the linear regression slope (-1/2*m*) of the S_{max} versus N_f plot on the log-log scale can be used to compute the material constant, *m*.

To determine the value of *n*, we need to use the solution in an intermediate state with partial damage, *D*, in equation (5). As evidenced from our experimental data as shown in **Figure 4**, *D* doesn't increase up to 10^4 loading cycles. Therefore, *D* is relatively small until the maximum number of life cycles is approached.

We can obtain constant *n* as described in the fatigue behavior of wood flour filled polypropylene composites section

$$n = \frac{2(1-K_{12})}{(D_1 - D_2 K_{12})} \quad (10)$$

where

$$K_{12} = \frac{N_1}{N_2}\frac{D_2}{D_1} \quad (11)$$

The remaining parameter, *C*, can then be determined using the plot of the normalized maximum stress versus the number of cycles at failure in equation (6) and the already known values of *m* and *n* (Tang et al., 2000).

Experimental Results and Damage Model Verification

Each set of fatigue experiments were carried out at the selected maximum loads until the samples failed. The applied load and the number of cycles at failure were recorded. These data were used to establish the *S-N* curves and to verify the damage fatigue model (6). The data were also employed to determine the value of *a* and *b* in equation (7).

Figure 5 displays the linear-fit lines of fatigue data versus applied maximum stress. The linear fit line for weathered HDPE composite sample is below that for unweathered sample. It appears that for a given maximum applied load, the number of cycles at failure for weathered sample is less than that for unweathered sample due to the chemical decomposition during the accelerated weathering. The small difference between the slopes for each set of test samples could be due to inability to statistically average out experimental variations by the limited number of samples.

Table 3 shows fatigue life at each *S* ratio and in **Figure 6**, the normalized maximum stress is showed against the number of cycles at failure on the log-log scale for each set of fatigue data obtained. In this figure, the symbols represent the experimental data and the *S-N* curves are obtained from the linear regression of the data. The R^2 values were found to be 0.94 and 0.91 at

unweathered and weathered HDPE composite samples, respectively. We also generate thick dotted line as a linear fit of unweathered HDPE composite to get the same *m* value in the analysis. The adjusted red line is still reasonable to fit the experimental data. The same fatigue data compared with wood flour filled polypropylene composite are also plotted as shown in **Figure 7**. The experimental data show that there is a strong linear relationship between *S* and $\log N_f$. **Figures 6** and **7** also reveal that under the same applied stress level, the fatigue life of the HDPE composite is longer than PP composite due to the ductility of the matrix polymer and the fatigue life of the weathered HDPE composite is relatively shorter than unweathered HDPE composite due to the chemical decomposition during accelerated weathering. Such chemical decomposition can cause not only reduced fatigue life but also more rapid growth of cumulative damage during the life cycle as shown in **Figure 8**. The pre-existing decomposition can cause more rapid propagation of the matrix crack and filler-matrix debonds.

The normalized *S-N* curve in **Figure 6** can be used to predict the fatigue life of the composite used in this research. To determine the *m* value, equation (9) is rewritten in a simple linear form ($y = a + bx$).

$$\log S = -\frac{1}{2m}\log((n+1)C(1-R)^m) - \frac{1}{2m}\log N_f \qquad (12)$$

where

$$a = -\frac{1}{2m}\log((n+1)C(1-R)^m)$$
$$b = -\frac{1}{2m}$$

The values of *a* and *b* are obtained from the separate fatigue experimental data obtained at 10-Hz at each set of samples and $m = -1/2b$. **Table 4** lists these values and their standard errors for each set of test samples.

When the values of *a* and *b* are substituted into equation (12), the *S-N* curve for the composite may be expressed as follows:

$$S^{2m} N_f = 10^{2am}$$

N_f can be expressed as a function of the *S* ratio:

$$N_f = \left(\frac{10^a}{S}\right)^{2m} \qquad (13)$$

In case of the unweathered and weathered samples, this equation can be expressed as

$S^{18.12} N_f = 438.01$ $\qquad$ $N_f = (1.40/S)^{18.12}$ and

$S^{18.12}N_f = 299.04$ $\quad\quad N_f = (1.37/S)^{18.12}$, respectively.

Figure 9 shows the predicted and experimental values for fatigue life at different exposure time. The experimental data generated from this research is in good agreement with the calculated model.

To calculate damage growth, intermittent residual modulus tests were performed. The value of n is determined from the slope of partial damage plot which is shown in **Figure 10** at different numbers of loading cycles under a given maximum load. This figure shows that when the damage becomes substantial, it increases at a constant slope but we may not accurately catch the number of cycles where the substantial damage starts because we only measure the partial damage at the beginning of each order of magnitude (10^3, 10^4, 10^5 *etc*.). This figure also shows that the damage growth within an order of magnitude of loading cycles (dD / $d\log N$) is constant approximately 0.3, therefore, for a given maximum applied load with two partial damages D_1 and D_2 measured at two respective numbers of loading cycles N_1 and N_2, we can obtain
$N_2 / N_1 = 10$

$$\frac{dD}{d\log N} = \frac{D_2 - D_1}{\log N_2 - \log N_1} = \frac{D_2 - D_1}{\log \frac{N_2}{N_1}} = D_2 - D_1 = 0.3$$

From **Figure 10**, D_1 starts from approximately 0.02 ~ 0.1, therefore,

$$\frac{D_2}{D_1} = \frac{D_1 + 0.3}{D_1} = 1 + \frac{0.3}{D_1} \quad , \quad 4 \le \frac{D_2}{D_1} \le 16$$

From (11), we may have

$$0.40 \le K_{12} \le 1.60$$

Meanwhile, from (4), n must be ≥ 1

$$n = \frac{2(1 - K_{12})}{(D_1 - D_2 K_{12})} \ge 1 \tag{14}$$

$$K_{12} \ge \frac{D_1 - 2}{D_2 - 2} \quad , \quad \frac{D_1 - 2}{D_2 - 2} = \frac{D_1 - 2}{D_1 + 0.3 - 2} \approx 1.18 \quad , \quad K_{12} \ge 1.18$$

We may have

$$1.18 \le K_{12} \le 1.60$$

Therefore we can obtain

$1.01 \le n \le 2.50$, $n = 2$

We can also obtain C from given m, n values. **Table 5** lists these values for each set of test samples.

Meanwhile, C as a function of exposure time may be written

$$C = C_1 + tC_2 \tag{15}$$

where C_1 and C_2 = constants and t = exposure time.

Substituting C into (5) and (6), we can obtain (16) and (17)

$$\frac{1}{n+1} - \frac{(1-D)^{n+1}}{n+1} = (C_1 + tC_2)(S_{max}{}^2(1-R))^m N \tag{16}$$

$$\frac{1}{n+1} = (C_1 + tC_2)(S_{max}{}^2(1-R))^m N_f \tag{17}$$

To determine the C_1 and C_2, we rely on experimental data at two different set of test samples (unweathered and weathered). By taking a logarithm on both sides of equation (17) and substituting the S_{max} and N_f for 0 and 2,000 hrs of exposure time, respectively, into the equation, two separate equations for respective 0 and 2,000 hrs can then be subtracted from each other.

$$\log(C_1 + 0 \cdot C_2) - \log(C_1 + 2000 \cdot C_2) = 2m(\log S_{max,(2000)} - \log S_{max,(0)}) = -0.16582$$

where $S_{max,(0)}$ and $S_{max,(2000)}$ = the maximum/ultimate stress ratios for 0 and 2,000 hrs exposure time, respectively

$$\frac{(C_1 + 0 \cdot C_2)}{(C_1 + 2000 \cdot C_2)} = 0.68263$$

$$1365.26 C_2 = 0.32 C_1$$

$$\frac{C_2}{C_1} = 0.00023$$

Equations (16) and (17) can then be rewritten

$$\frac{1}{n+1}-\frac{(1-D)^{n+1}}{n+1}=C_1(1+0.00023\cdot t)(S_{max}{}^2(1-R))^m N \tag{18}$$

$$\frac{1}{n+1}=C_1(1+0.00023\cdot t)(S_{max}{}^2(1-R))^m N_f \tag{19}$$

Using the experimental data to determine the material constants and from (19), we have obtained the equation (20) for a wood flour reinforced HDPE composite using variable *t* which is exposure time, therefore we can use this equation to predict fatigue life with different UV exposure time

$$S^{18.12}N_f=\frac{438.09}{1+0.00023\cdot t} \tag{20}$$

where S_{max} = normalized stress to respective static ultimate strength.

From the integration of fatigue model (18) and using partial damage growth, we can obtain residual modulus and partial damage equation for a given maximum applied load after *N* loading cycles. The pre-existing and partial damage during the weathering process can be calculated using these equations.

$$E=E_0\left(1-\frac{S^{18.12}N(1+0.00023\cdot t)}{438.09}\right)^{\frac{1}{n+1}} \tag{21}$$

$$D=1-\frac{E}{E_0}=1-\left(1-\frac{S^{18.12}N(1+0.00023\cdot t)}{438.09}\right)^{\frac{1}{n+1}} \tag{22}$$

Figures 11 and **12** show the predicted and experimental data of residual modulus and partial damage of the composite. The experimental data generated from the composite used in this research is in good agreement with the calculated model. The model can be used to predict the fatigue life of the particle-reinforced thermoplastic polymeric composites subjected to an applied load in different UV exposed environments and to predict the residual flexural modulus after certain number of cycles of service at a given load.

Figure 13 shows that the partial damage calculated from intermittent static modulus test, predicted model from damage growth and complex MOE from actual continuous fatigue test are in good agreement with each other. Damage model based on the intermittent static test can be used to predict complex MOE from actual fatigue test.

Table 6 and **Figure 14** summarize the static mechanical properties of the composite used in this research. It shows approximately 28% decrease of its ultimate strength in the weathered samples as compared to the unweathered samples and approximately 56% decrease of its flexural modulus due to the pre-existing decomposition during the weathering exposure.

Conclusions

From the experimental data and cumulative damage calculation, we can conclude that accelerated weathering causes decreased flexural strength, modulus, fatigue life and also causes rapid damage growth. Fatigue life decreased with increasing stress ratio, and also decreased with increasing exposure time due to the chemical decomposition during accelerated weathering. Such chemical decomposition can cause not only reduced fatigue life but also more rapid growth of cumulative damage during the life cycle. A fatigue model based on the cumulative damage with cyclic loading is verified with experimental data for wood flour reinforced high-density polyethylene composite. The cumulative fatigue damage per cyclic loading, residual modulus in terms of partial damage and fatigue life of the composites are described as functions of applied maximum stress, stress amplitude, exposure time of accelerated weathering, damage and material constants. The material constants used in the model are determined from the experimental data. Intermittent residual modulus data, complex MOE from cyclic load test and cumulative damage model are in good agreement with each other so that can be used to predict the fatigue life and damage of a wood flour filled high-density polyethylene composite at an applied load and to predict the residual modulus after certain number of cycles at a given load in various structural deck boards and pedestrian bridges in different UV exposed environments.

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Tables

Table 1. Product details and quantities for extruded materials

Material	Quantities	Manufacturer	Product
HDPE	31%	Equistar petrothene	LB 0100-00
Wood flour	58%	American Wood Fibers	#6020
Talc	8%	Luzenac	Nicron 403
Zinc stearate	2%		
EBS	1%		

Table 2. Stresses applied in each fatigue test

Sample	Maximum Stress (psi)	Ultimate MOR (psi)	S ratio ($\sigma_{max}/\sigma_{ult}$)
Unweathered HDPE composite	2078	2969	0.70
	2227	2969	0.75
	2375	2969	0.80
	2524	2969	0.85
	2672	2969	0.90
Weathered HDPE composite	1501	2144	0.70
	1608	2144	0.75
	1715	2144	0.80
	1822	2144	0.85
	1930	2144	0.90

Table 3. Fatigue test data for each exposure time of accelerated weathering

	Wood flour-HDPE					
Freq.	Unweathered (0 hrs exposure time)			Weathered (2,000 hrs exposure time)		
	R-ratio	S	Fatigue life	R-ratio	S	Fatigue life
10-Hz	0.10	0.70	186,040	0.13	0.69	244,255
	0.10	0.68	285,403	0.11	0.71	90,183
				0.11	0.69	154,704
	0.10	0.75	98,531	0.12	0.73	131,676
	0.11	0.77	54,459	0.10	0.75	91,304
	0.10	0.73	138,598	0.11	0.77	22,889
	0.10	0.81	15,369	0.10	0.79	14,789
	0.10	0.80	21,964	0.10	0.80	15,402
	0.11	0.81	15,531	0.10	0.80	16,362
	0.11	0.84	6,463	0.10	0.85	3,465
	0.13	0.86	25,694	0.10	0.83	12,683
	0.10	0.86	7,135	0.11	0.83	5,265
	0.11	0.88	3,121	0.10	0.85	14,840
	0.13	0.91	1,994	0.11	0.88	2,922
	0.10	0.98	361	0.11	0.86	7,773
				0.11	0.88	3,827

Table 4. Linear constants and *m* values for each set of test samples

Sample	*a*	Standard error	*b*	Standard error	*m*	Standard error
Unweathered	0.15	0.02	-0.06	0.004	9.06	0.63
Weathered	0.14	0.02	-0.06	0.005	9.06	0.77

Table 5. Material constants *m*, *n* and *C* values for each set of test samples

Sample	*m*	*n*	*C*
Unweathered	9.06	2	0.002
Weathered	9.06	2	0.003

Table 6. Static mechanical properties of the composite

	Unweathered HDPE composite	Weathered HDPE composite
Exposure time (hrs)	0	2,000
MOR (psi)	2,969	2,144
MOE (psi)	459,321	203,159
Displacement at break (in)	0.07	0.12
Strain at break (in/in)	0.01	0.02

Figures

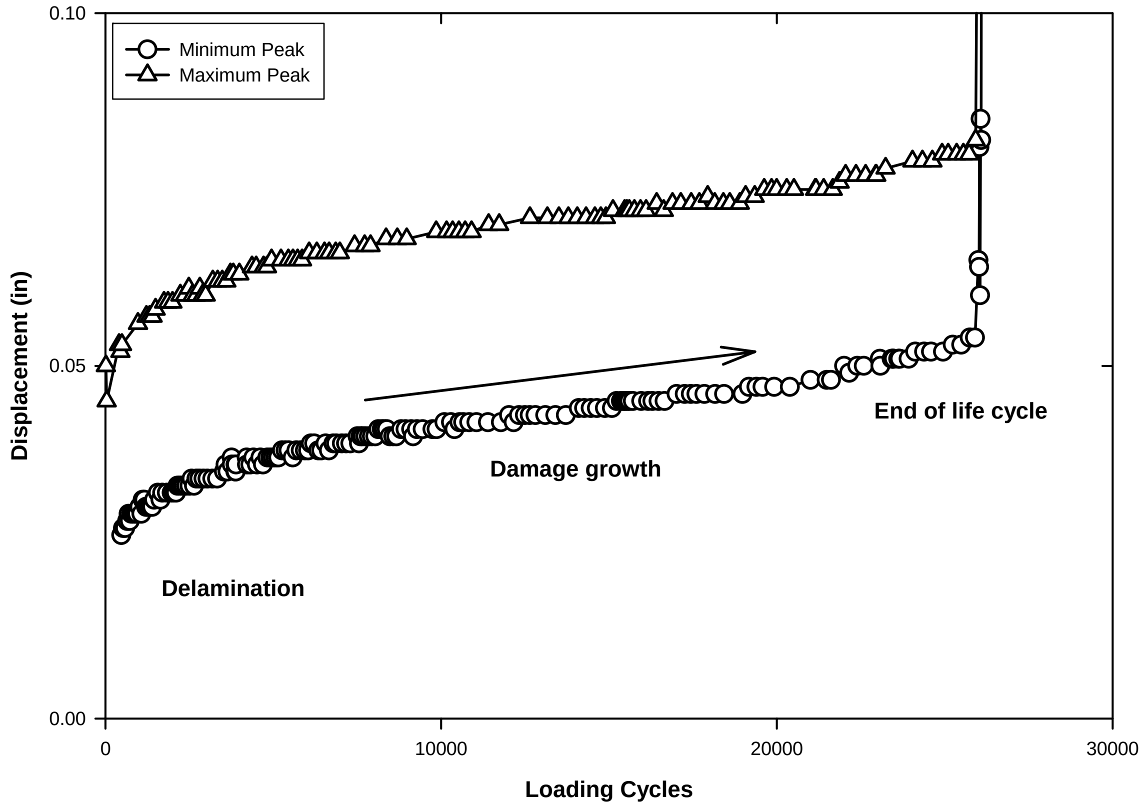

Figure 1. Typical fatigue progress of the composite.

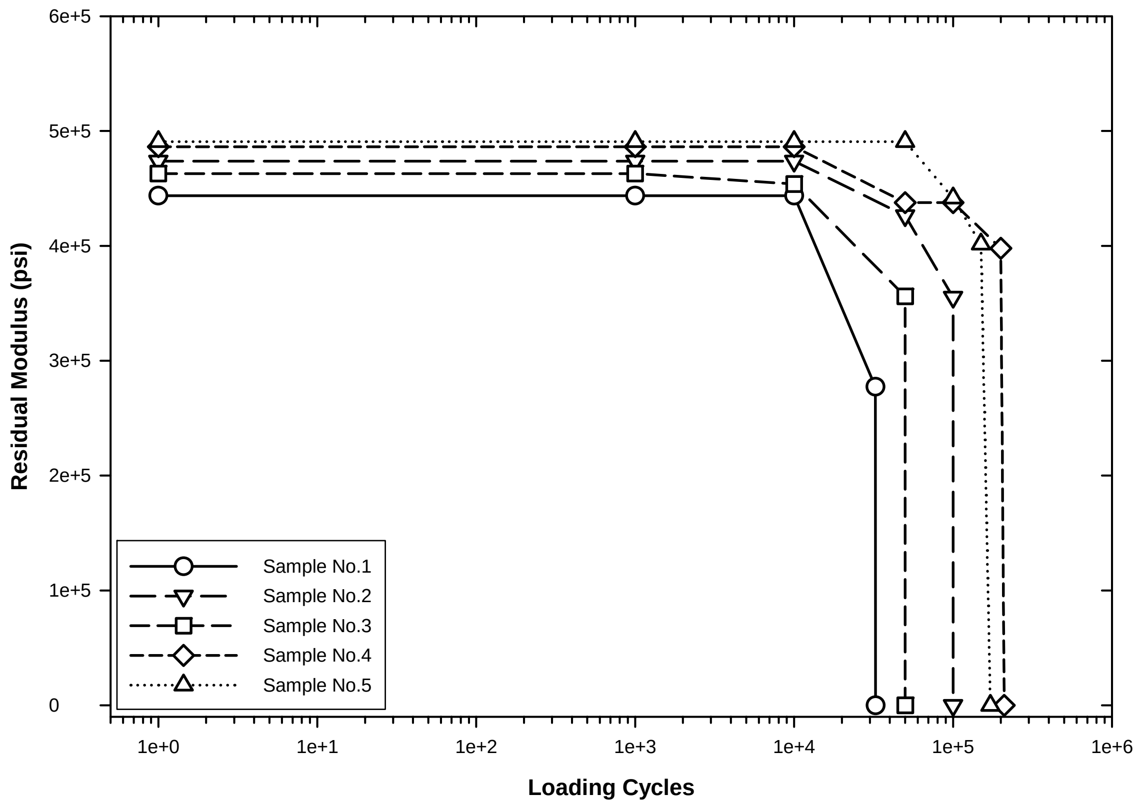

Figure 2. Residual modulus at 75% of ultimate load.

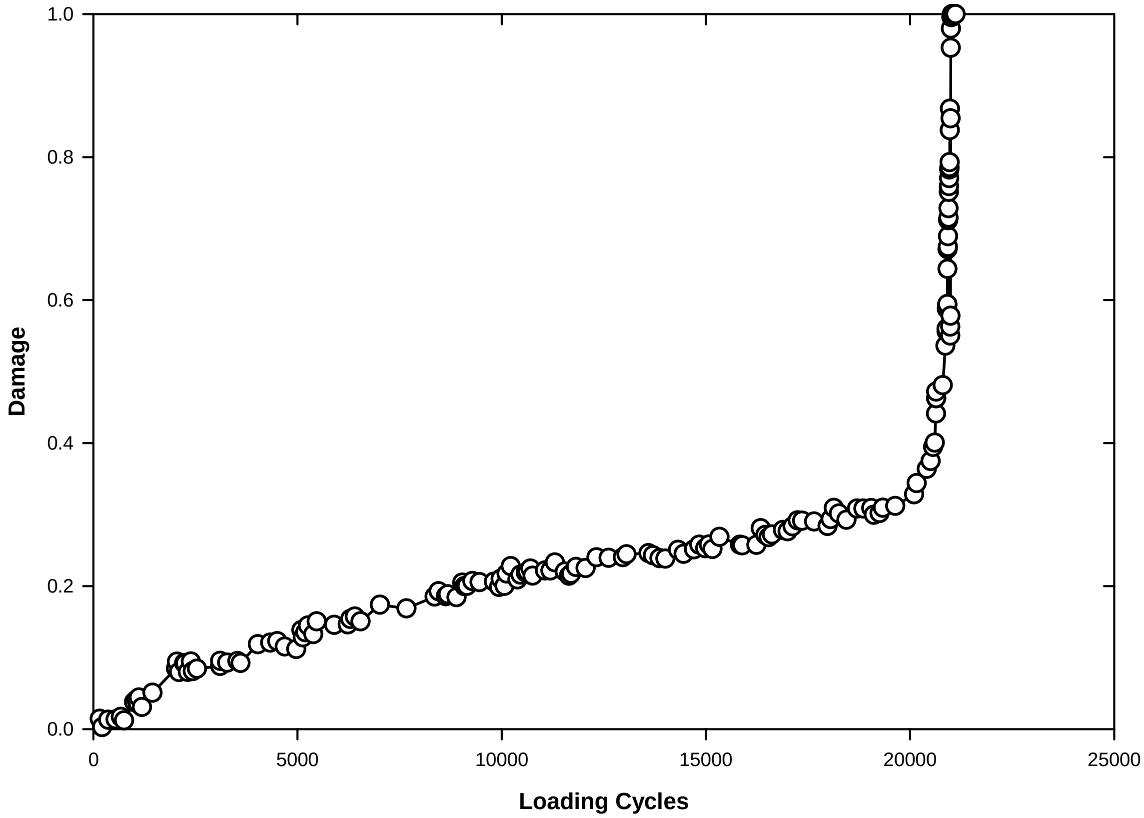

Figure 3. Cumulative damage versus number of cycles at 80% of ultimate load.

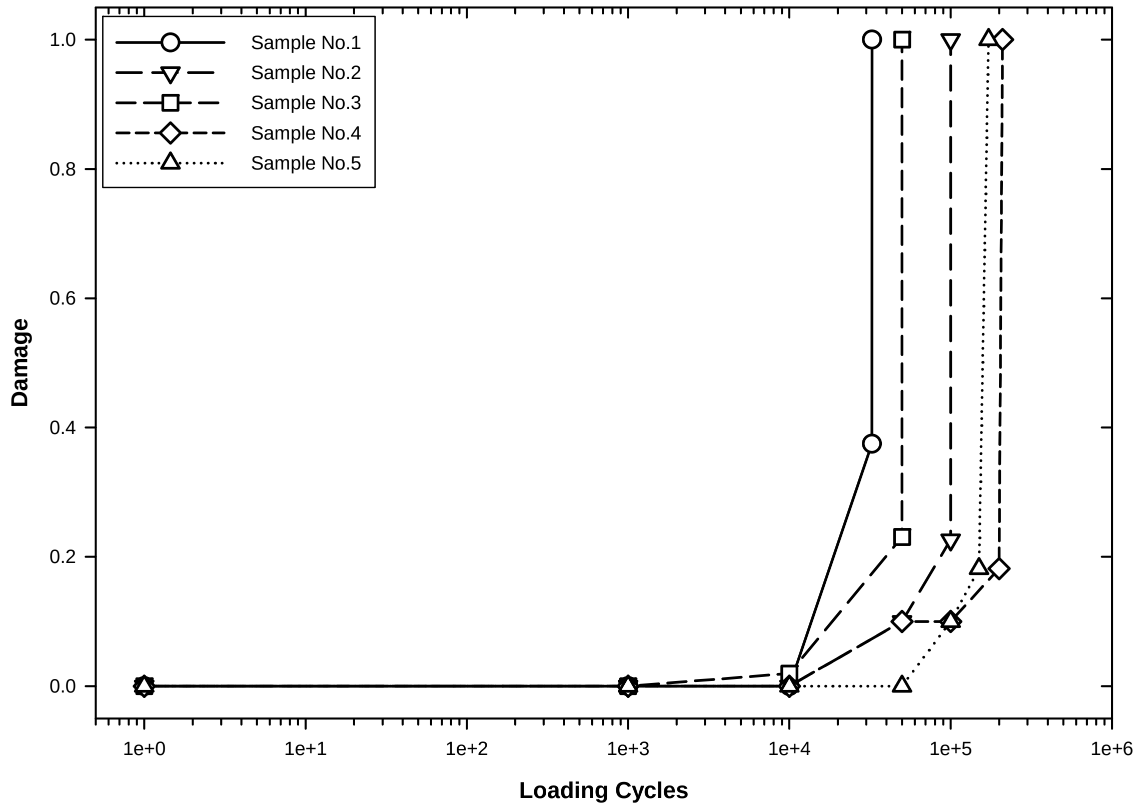

Figure 4. Partial damage at 75% of ultimate load.

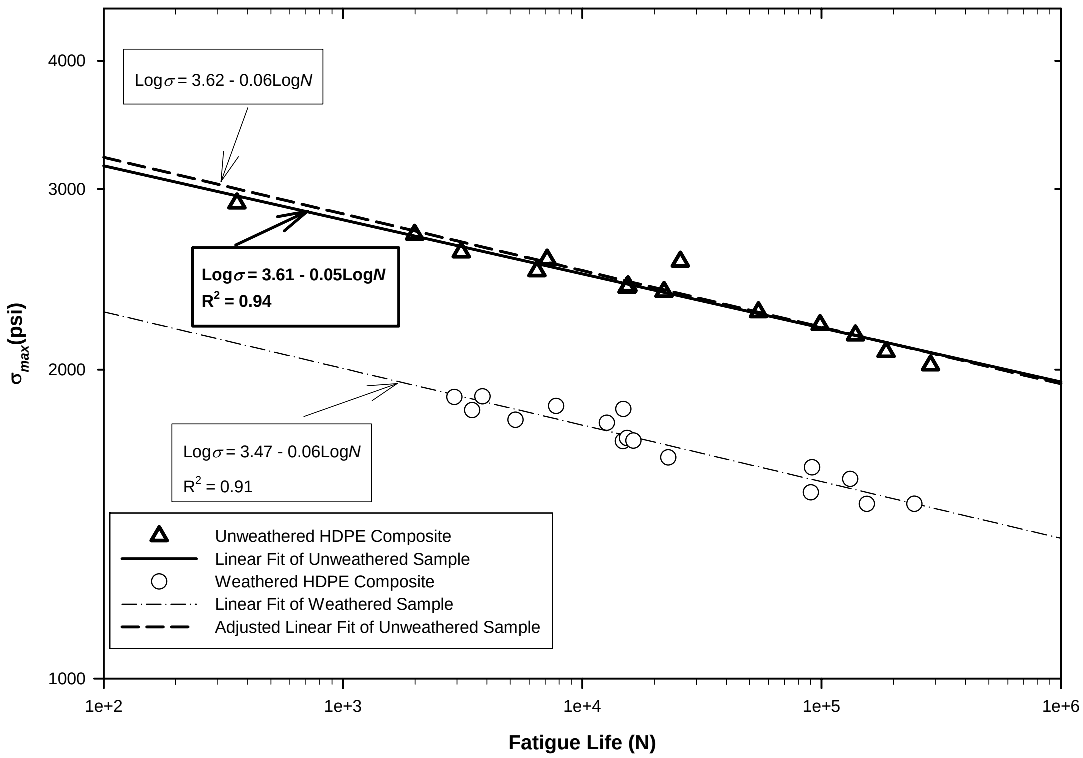

Figure 5. Fatigue life versus applied maximum stress at 10-Hz for weathered and unweathered samples. (log-log scale)

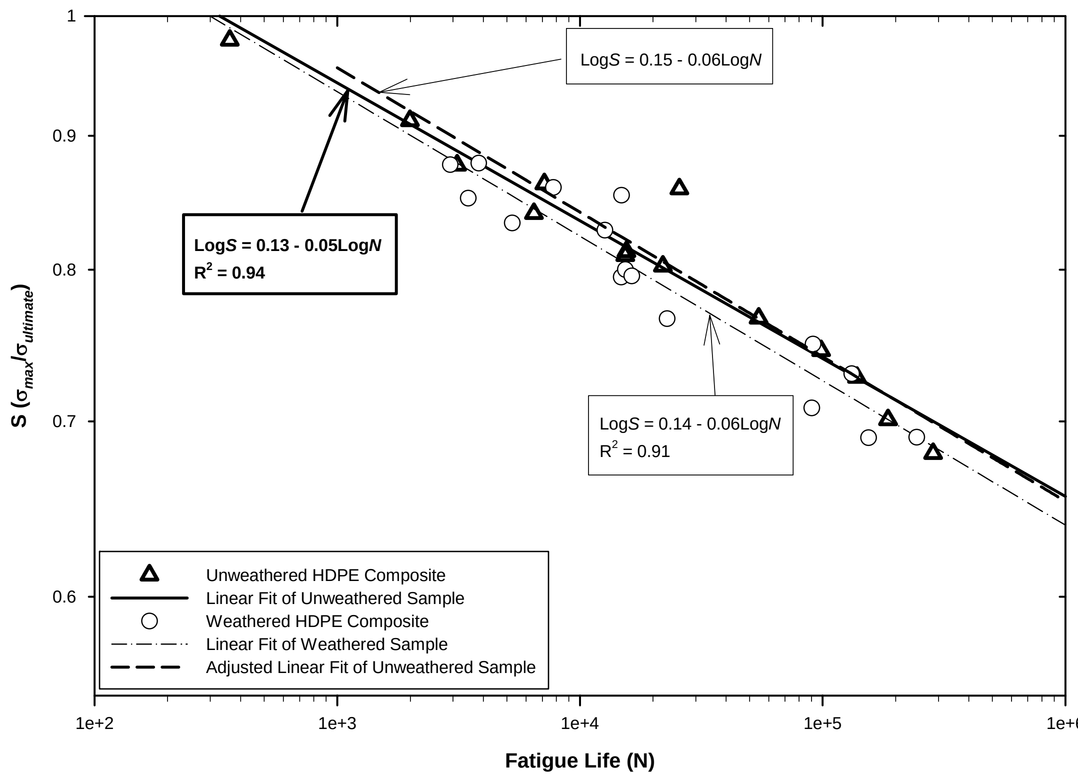

Figure 6. Fatigue life at 10-Hz for weathered and unweathered samples. (log-log scale)

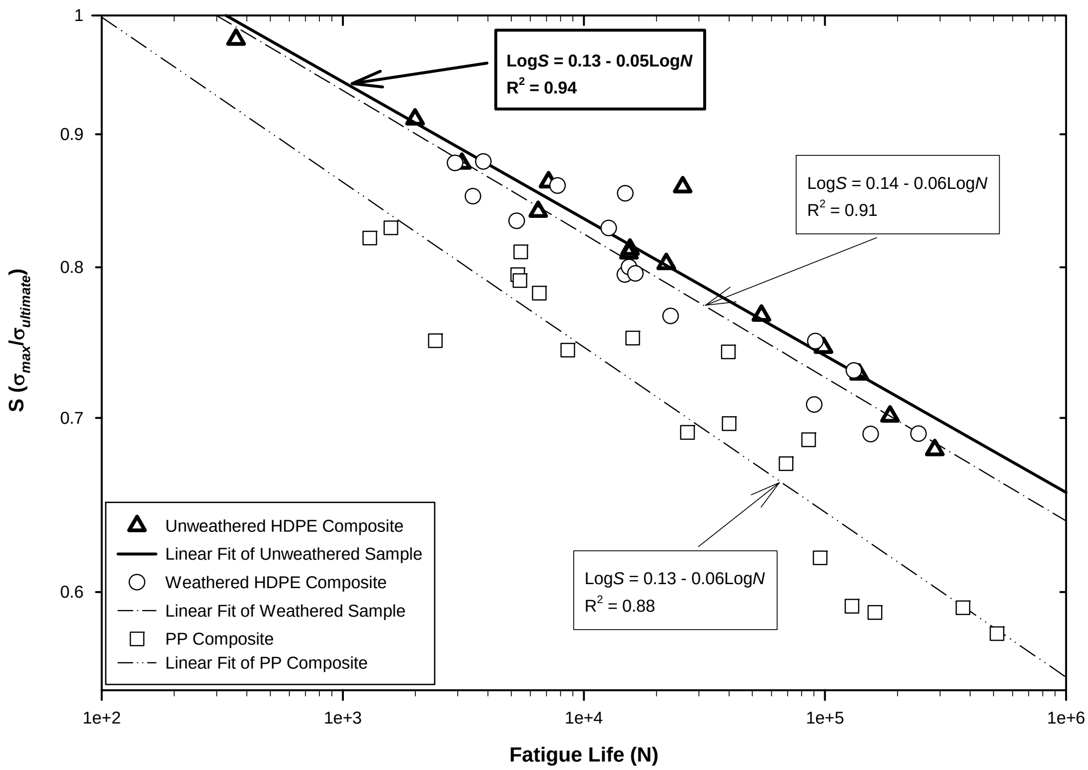

Figure 7. Fatigue life at 10-Hz for wood flour-HDPE and -PP composite samples.

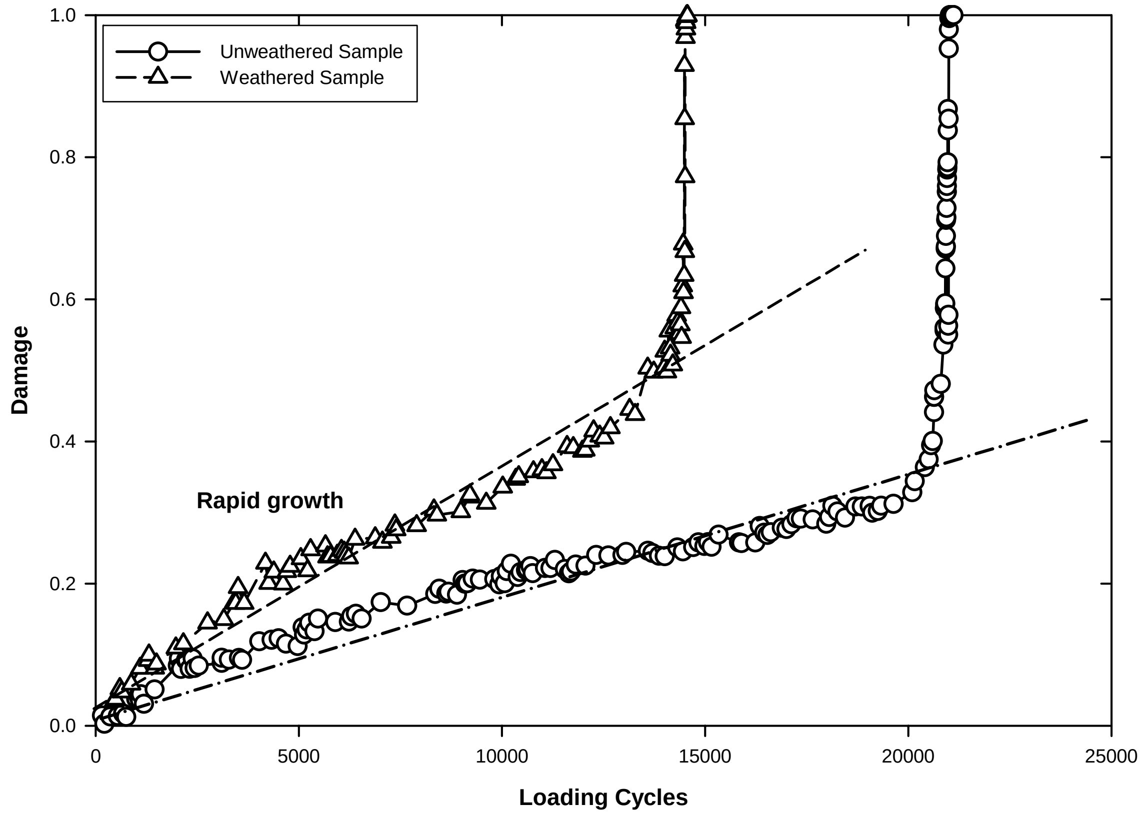

Figure 8. Comparison of damage growth versus number of cycles at 80% of ultimate load between weathered and unweatherd composite sample.

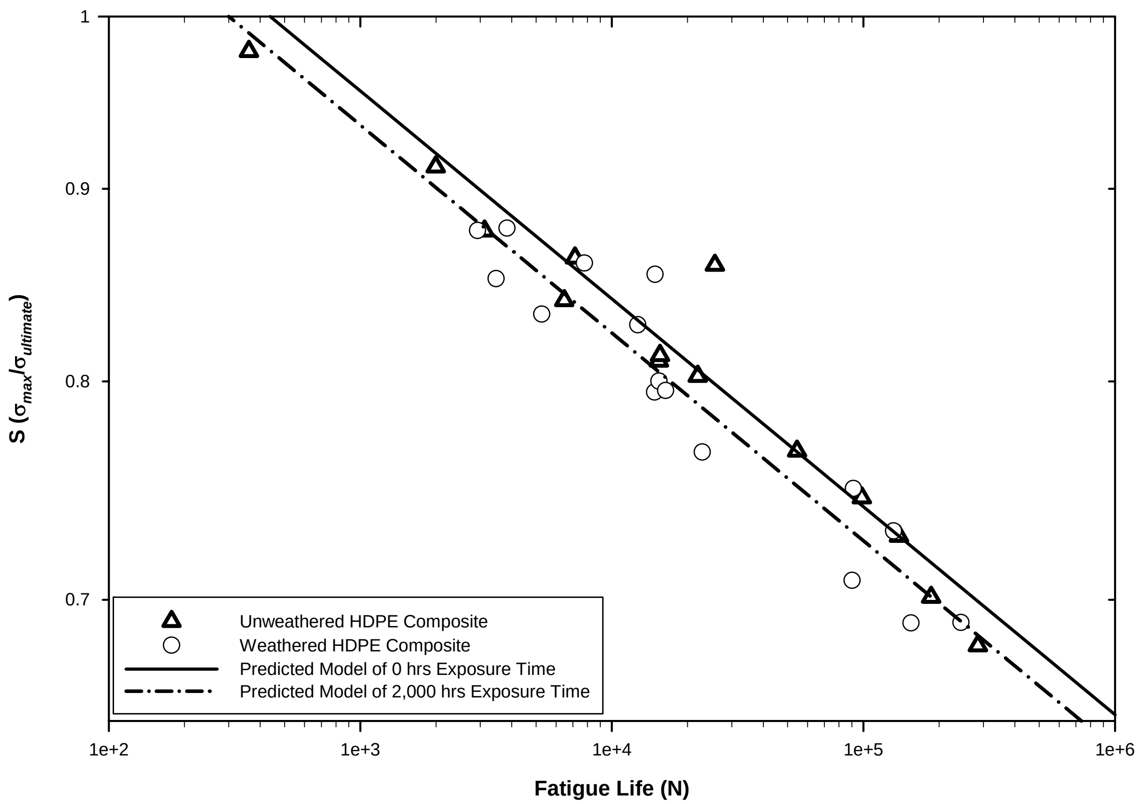

Figure 9. Predicted and experimental values for fatigue life at different exposure time.

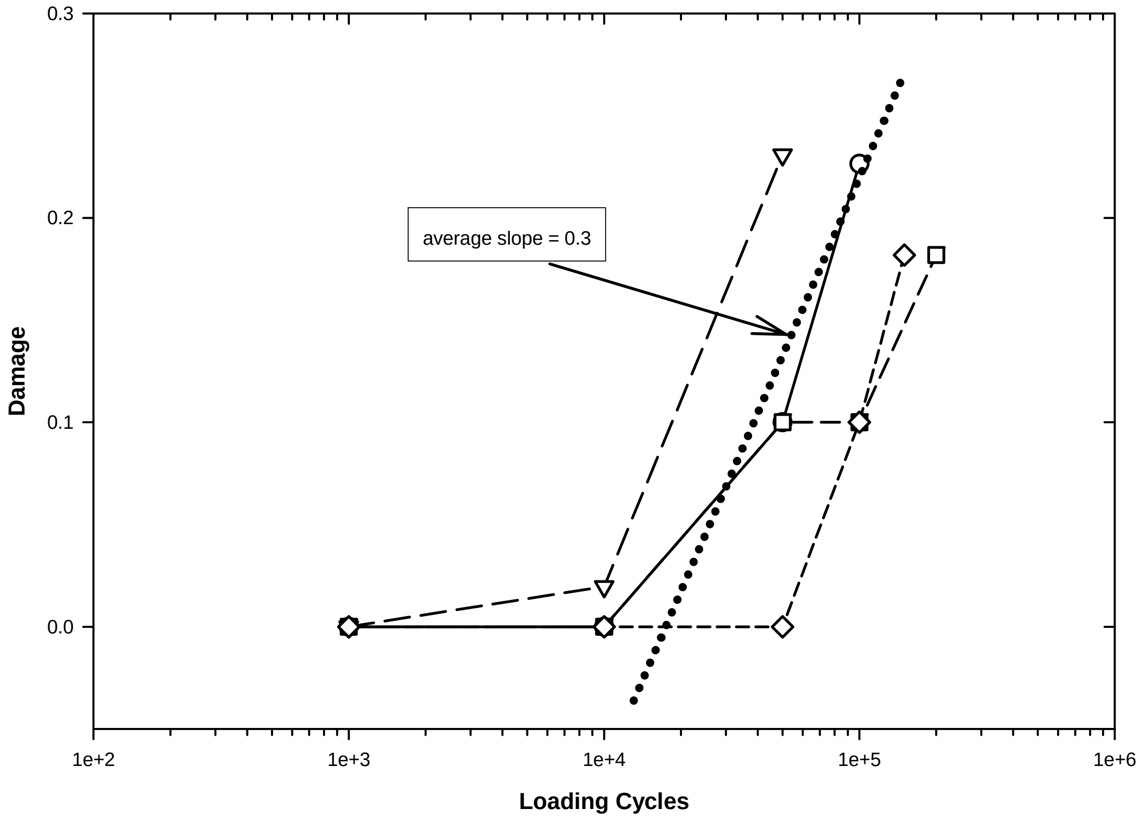

Figure 10. Partial damage growth at selected loading cycles and 75% of ultimate load.

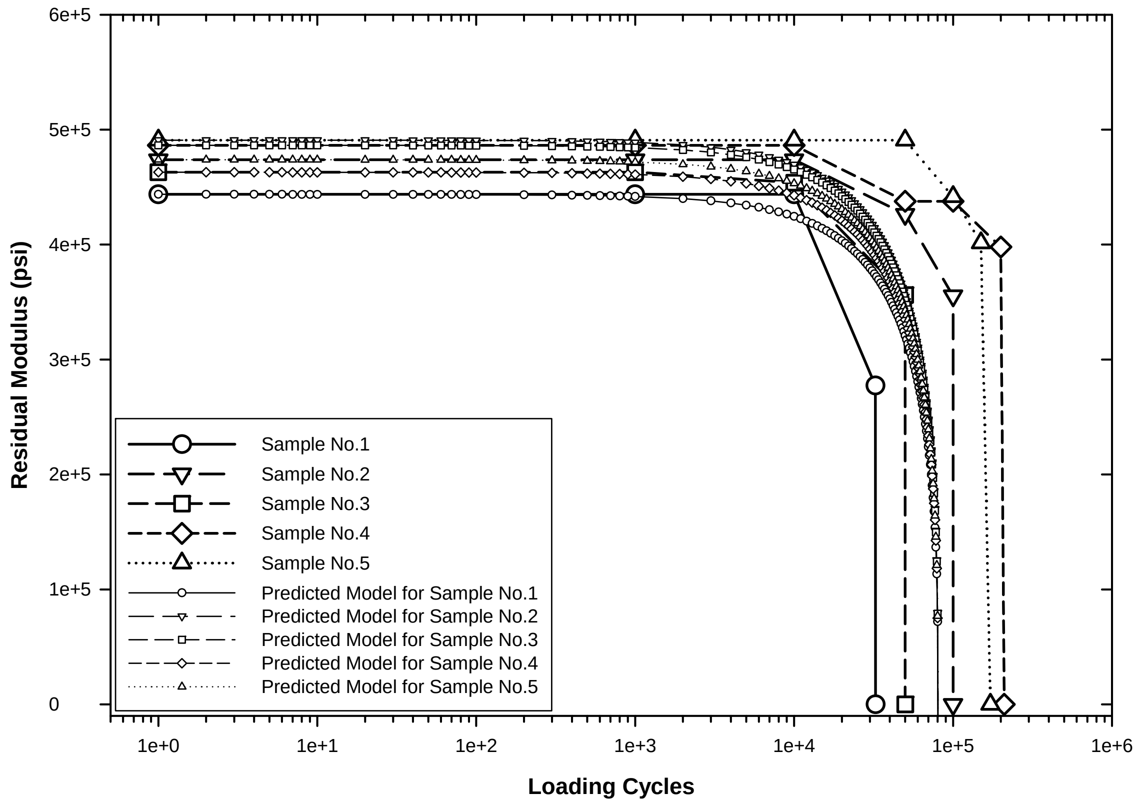

Figure 11. Predicted and experimental values for residual modulus of the composite at 75% of ultimate load.

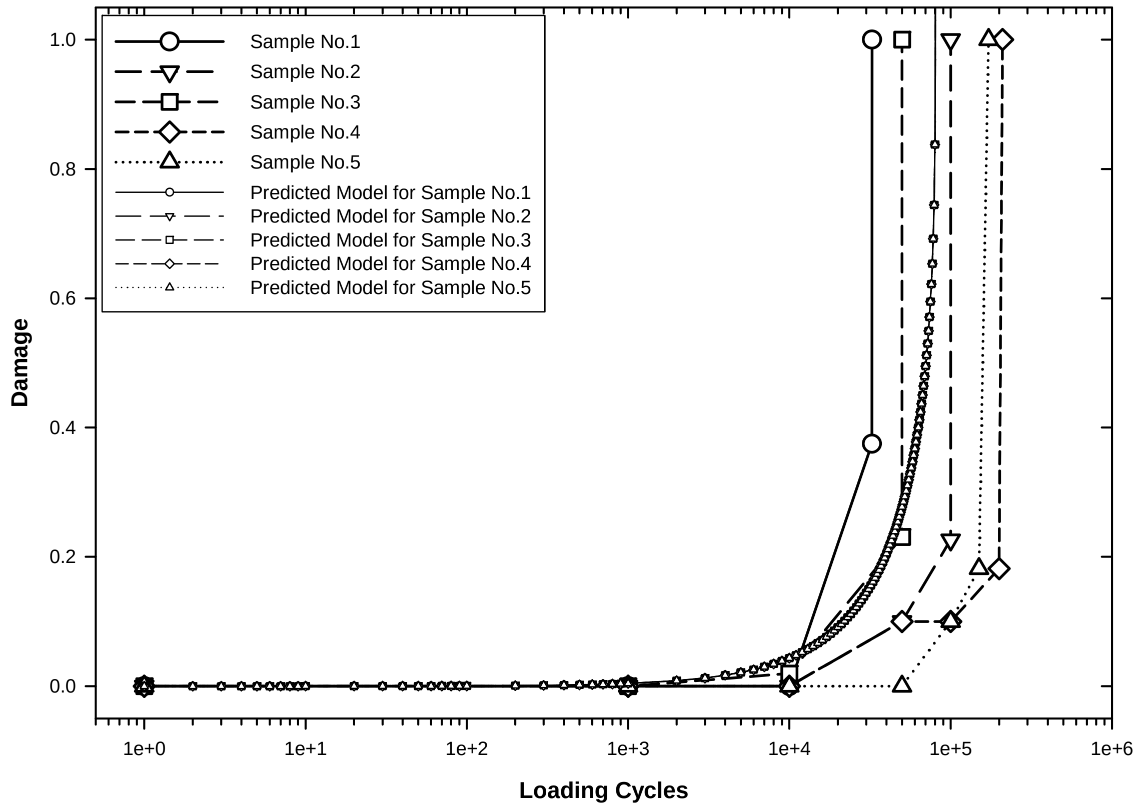

Figure 12. Predicted and experimental values for partial damage of the composite at 75% of ultimate load.

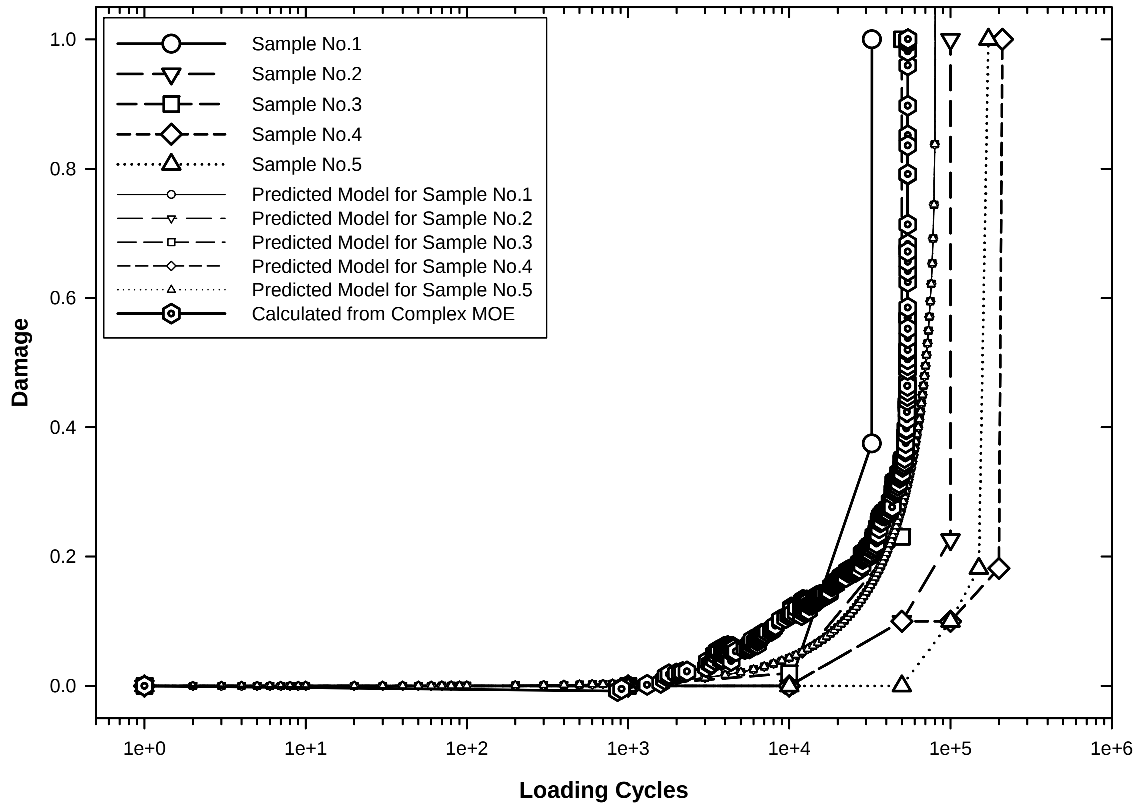

Figure 13. Predicted and experimental damage data from intermittent residual modulus test and damage calculated from complex MOE.

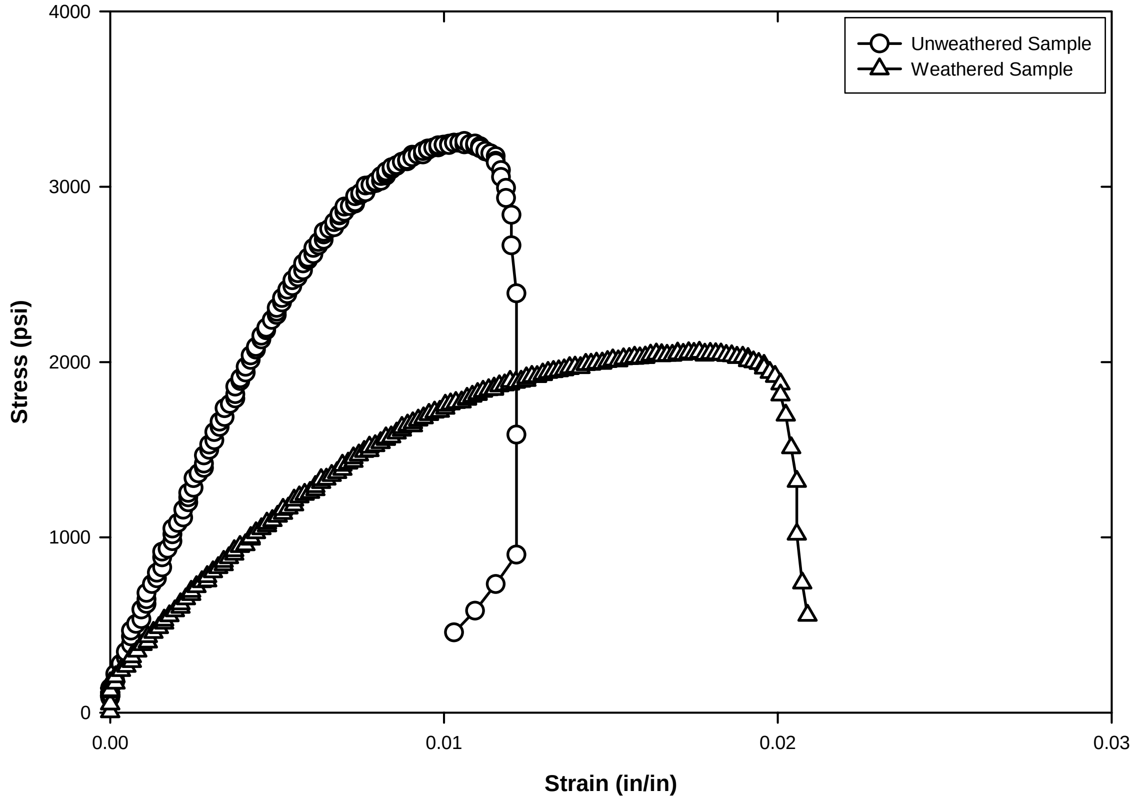

Figure 14. The stress-strain curves of weathered and unweathered samples.

Durable Wood Composites for Naval Low-Rise Buildings

Effects of Environmental Temperature and Damage Model Verification for Fatigue Behavior of Wood Flour Filled Polypropylene Composites

Siding and Trim Components

Task S5 – Siding and trim components with improved weathering performance

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Abstract

Cumulative damage model is verified for predicting the fatigue life of wood flour filled polypropylene composites and general fatigue model was modified to describe the influences of environmental temperature on the fatigue life. The model incorporates applied maximum stress, stress amplitude, environmental temperature, residual static modulus, and material constants as parameters.

Residual modulus and partial damage were measured at a certain numbers of loading cycles under a given maximum load by intermittent static test to calculate damage growth. Wood flour-polypropylene composite samples were tested in flexural fatigue and the model is verified using damage assessment. Both the residual static modulus at predetermined loading cycles and the number of cycles at which the samples fail are measured.

Under the same applied stress level, the fatigue life of the composite in the lower temperature range is shorter than that at room temperature, due to the brittle and glassy properties of the matrix polymer. The fatigue life of the composite in the higher temperature range is longer than that at room temperature, due to the ductile property of the matrix polymer.

Damage growth in the higher temperature range was slowed down due to the ductile property of the matrix polymer. The experimental data generated from the intermittent static modulus test is in good agreement with the calculated model.

Introduction

Polypropylene is a relatively inexpensive engineering thermoplastic polymer and has many potential applications in automobiles, appliances and other commercial products. It is often combined with wood and other natural fillers to improve its modulus, creep resistance and impact strength (Zhou et al., 2005). It might be able to combine the favorable performance and low cost attributes of both natural fillers and thermoplastic polymers, so that such natural filler reinforced polyolefin composites can be as an alternative to preservative-treated timber in both residential and commercial applications.

During the past years, wood and other natural filler filled thermoplastic polymer composites have been increasingly used a number of applications in structures. Many of those structures may experience cyclic loading over long time, so that they are prone to encounter unexpected fatigue failure in service (Zhou et al., 2005). Mechanical fatigue is the most common type of failure of structures in service, both for homogeneous and composite materials (Gamstedt et al., 1999). The extensive use of highways and the growing frequency of heavy trucks contribute significantly to fatigue damage (Wang, 2000). Because between 80 and 90% of structural failures occur from fatigue, the importance of the cyclic loading conditions in determining structural performance will be increased. Therefore, fatigue is an issue that needs to be considered in the design of structural bridge decks (Gong and Smith, 2003).

A potential problem with using thermoplastic polymer composites in structural applications involves their fatigue reliability under various environmental and loading conditions. Fatigue reliability is an area of research that is gaining increased attention for civil structures. Specifically for WPCs, minimal research exists regarding fatigue. If WPCs are to be accepted by industry as a building material, the service life of the material is an important parameter to qualify the material as a viable solution (Slaughter, 2004). Since fatigue failure is a major concern in designing the structures, it is important to establish the fatigue properties of polymers to be used in these structures.

Previous research has investigated the use of WPCs as an alternative to preservative treated wood members in military and civilian marine structures (Haiar,2000) and a research focused on the use of WPC members for waterfront facilities, including a deckboard and chock members that were installed at U.S. Navy bases (Haiar et al.,2001) was conducted. In many transportation and pedestrian structures, repeated loading causes failure of the material, so that there is an imminent need to develop mathematical analysis and methodology for assessing the safety and reliability of using polymeric composites in these applications. One of the most important issues in regard to using polymeric composites in such structural applications is their fatigue reliability in different environmental condition such as temperature. Fatigue damages in polymeric composites for non-structural applications have been widely investigated (Reifsnider 1991; Talreja 1987; Jang 1994; Martin 1995), but there is little quantitative research on the effects of civil engineering environments, namely, temperature and loading on the fatigue of polymeric composites.

In this research, we will present the results of a fatigue test conducted on a wood flour filled polypropylene composite. The main purpose of this research was to evaluate fatigue properties of the composite using damage assessment, consider the effects of environmental temperature on the fatigue performance of the composite, and simulate residual static modulus and partial damage at a certain number of cycles during the fatigue life. Small coupon samples of wood flour-polypropylene composites were tested in flexural fatigue to evaluate the influences of environmental temperature and stress ratio on the fatigue life. The unexpected thermal failure caused by internal heating can occur during the fatigue life cycle in the full-scale deck board, therefore we selected small sized coupon to prevent internal heating. This research presents the experimental verification of a cumulative fatigue damage model subjected to flexural loading in each of three environmental temperatures. Cumulative damage model was verified using experimental data to describe damage growth in terms of material constants, stress ratio and environmental temperature.

Objectives

The research presented herein was conducted with the objective of advancing the acceptance and knowledge of fatigue properties of wood flour reinforced PP composite. The specific goals were to:

1) Verify existing damage model to simulate fatigue life of the wood flour reinforced thermoplastic polymer composite,
2) Modify general fatigue damage model to evaluate effects of environmental temperature on fatigue properties of wood flour/PP composite, and
3) Evaluate damage growth using residual modulus at a certain number of cycles by intermittent static test during the life cycle.

Materials and Methods

Flexural cyclic load tests were performed to assess the fatigue response of a WPC formulation with different *S* ratios ($\sigma_{max}/\sigma_{ult}$ ratio) and temperatures. Commercially available 60-mesh pine wood flour was obtained and dried in a steam tube dryer to a moisture content of approximately 2%. The formulation was composed of 58.8% wood flour, 33.8% polypropylene (PP), 4.0% talc, 2.3% maleated polypropylene (MAPP), and 1.0% lubricant by weight. **Table 1** summarizes the details of each of the components provided by the manufacturers. The materials were dry blended in powdered form using a 4-ft (1.2-m) drum mixer in a series of 55-lb (25-kg) batches. An 86-mm conical counter-rotating twin-screw extruder (Cincinnati-Milacron TC86) operating at 5 to 12 rpm was used for the production of the required sections. Triple box, hollow sections were extruded with an 86-mm conical twin screw extruder. A prearranged screw and barrel temperature profile (**Table 2**) was maintained throughout the extrusion process. The extrusion quality was enhanced by the use of a stranding die (Laver, 1996). The extruded profile has a nominal wall thickness of 0.4-in (1.02-cm) and nominal outside dimensions of 1.8-in (5-cm) in depth and 6.5-in (17-cm) in width. Test samples were cut from the flange of a standard triple box section and machined to a uniform thickness of 0.21-in (5.33-mm). The samples were machined to size and environmentally conditioned at 70-degrees F (21.1° C) and 50-percent RH. Testing was performed in an environmentally conditioned chamber maintained at 70-degrees F (21.1° C), -22-degrees F (-30° C) and 150-degrees F (65.6° C). Coupon flexural fatigue tests were carried out on samples with dimensions that were: 1.18-in. (30-mm) wide, 0.21-in. (5.33-mm) deep, and 4.36-in. (110.74-mm) long for an L/D ratio of 16. The applied spans were 3.36-in. (85.34-mm) long. A 1-kip load cell attached to a servo-hydraulic universal testing machine (MTS model 602.10A-01) was utilized for the application of the load and the data was acquired in real time by means of a computer. Temperature data was also acquired from the test samples in order to monitor the internal heating during the test. The modulus of rupture (MOR) values, obtained from the static tests, were used as a reference stress level in the determination of the applied maximum loads.

The fatigue tests consisted of applying controlled levels of cyclic stress using a servo-hydraulic, universal testing machine set to operate in load-control mode. Loads were applied to three replicate samples for each maximum stress level. The applied maximum stress levels ranged from approximately 45 to 80-percent of the ultimate static strength and the minimum stress levels were approximately 10-percent of each of the maximum stress levels. Namely, maximum stress to ultimate stress ratios (*S* ratios) of 0.45 to 0.8 and a minimum stress to maximum stress ratio (*R* value) of 0.1 were applied. The stresses applied in each test are reported in **Table 3**. During testing, each sample was loaded to

the prescribed maximum/minimum stress levels and these loads were maintained until break occurred. A frequency of 10-Hz was used to obtain meaningful results within a reasonable time.

Residual modulus and partial damage were measured at a certain numbers of loading cycles under a given maximum load by intermittent static test to calculate damage growth. Fatigue loading was stopped and static flexural tests were performed right after beginning of each order of magnitude (10^3, 10^4, 10^5 *etc*.). Residual modulus can be calculated from the slope between 20 and 40% of ultimate stress in the stress-strain curve. When the applied stress reaches 40% of ultimate stress, static loading was stopped and fatigue loading restarted immediately to prevent load release of each samples.

Derivation of Fatigue Damage Model

A model of the cumulative damage as a function of the number of loading cycles was suggested in a previous study (Tang et al., 2000). Matrix cracks occur early in the fatigue process and are due to the high concentration of stress. As the number of cracks increases, stress redistribution reduces the initiation of new cracks and the damage appears to grow at a constant rate as the cyclic loading continues. Interfacial debonding and breaking start and gradually increase at the point where damage occurs. The extent of interfacial debonding and breakage increases due to the continuing growth of the matrix cracks. As the breakage progresses and intensifies, the rate of interfacial debonding increases rapidly and the composite ultimately ruptures.

The change in the modulus has been commonly used to express the state of damage in polymer composites (Ye, 1989; Plumtree and Shen, 1991; Subramanian et al., 1995). The cumulative damage, *D*, can be defined as

$$D = 1 - \frac{E}{E_0} \quad , \quad \frac{dD}{dE} = f(D)$$

where E = residual modulus and E_0 = initial modulus.

The growth of damage under fatigue loading can be described as a function of the extent of damage and a set of parameters that characterize the mechanical environment such as the minimum/maximum stress ratio, frequency, temperature, *etc*. It is possible to define the incremental damage per loading cycle as a function of the cumulative damage, *D*, and a constant that may be dependent on the minimum/maximum stress ratio and the temperature. This function may be derived from the general plot of the cumulative damage versus the number of fatigue cycles (Ye, 1989; Plumtree and Shen, 1991). The derivative of the function rapidly decreases at the beginning, then remains constant as the fatigue loading continues, and rapidly increases near the end of the life cycle (Tang et al., 2000). The initial damage growth per loading cycle may be mathematically expressed as following function;

$$\frac{dD}{dN}=\frac{C_1}{D^{n1}}$$

where N = number of loading cycles

C_1 and n_1 = constants and $n_1 > 1$.

The damage growth near the end of the life cycle before failure may be expressed as

$$\frac{dD}{dN}=\frac{C_2}{(1-D)^{n2}}$$

where C_2 and n_2 = constants and $n_2 > 1$.

Thus, the general fatigue model may take the form

$$\frac{dD}{dN}=\frac{C_1}{D^{n1}}+\frac{C_2}{(1-D)^{n2}} \tag{1}$$

However, our experimental data and previous research (Tang et al., 2000) on the cumulative damage, D, as a function of the number of loading cycles, N, for the composite do not show any initial weakening of the material strength until the number of loading cycles exceeds 10^4 as shown in **Figure 1**. Further, the experimental data on the initial damage do not reveal any evidence of abrupt growth. Instead, the data show smooth and gradual increases in the amount of damage as shown in **Figure 2**. This result is similar to that obtained in previous studies of fiber reinforced composites, which showed little degradation in the modulus (Tang et al., 2000; Kadi and Ellyin 1994). Therefore, for the composite material used in this research, C_1 is negligible in comparison with C_2. Consequently, the damage rate per loading cycle may be expressed as

$$\frac{dD}{dN}=\frac{C}{(1-D)^{n}} \tag{2}$$

Besides the state of damage, the maximum stress and stress amplitude may have substantial effects on the damage growth (Wnuk, 1974a,b; Spearing et al., 1992; Thionnet and Renard, 1994). Likewise, the temperature, T (Ye, 1989), and frequency, f, can also affect the fatigue damage (Wnuk, 1974b). Therefore, the variable, C, in equation (2) can be expressed a function of the maximum stress, stress amplitude, temperature and frequency, such that:

$$C=C(\sigma_{max},\sigma_{amp},T,f)$$

In previous studies (Wnuk, 1974a,b), the power form was used to describe the fracture growth in the fatigue process in rate sensitive solids. Finally, the variable, C, in equation (2) may be expressed as

$$C = \hat{C}(T, f)F(\sigma_{max}, \sigma_{amp}) = \hat{C}(T, f)\sigma_{max}{}^{m1}\sigma_{amp}{}^{m2}$$

To make the above equation treatable, we further assume that $m_1 = m_2 = m$. Accordingly, equation (2) may be rewritten as

$$\frac{dD}{dN} = \hat{C}\frac{(\sigma_{max}\sigma_{amp})^m}{(1-D)^n} \tag{3}$$

where $\hat{C}$, m, and n = material constants

σ_{max} = maximum stress, σ_{min} = minimum stress

σ_{amp} = cyclic stress amplitude, equal to (σ_{max} - σ_{min}).

We can express the maximum stress and stress amplitude, normalized to the ultimate strength, σ_{ult}, and the minimum to maximum stress ratio, R, as follows:

$$S_{max} = \frac{\sigma_{max}}{\sigma_{ult}}$$

$$S_{amp} = \frac{\sigma_{amp}}{\sigma_{ult}} = \frac{\sigma_{max} - \sigma_{min}}{\sigma_{ult}} = \frac{\sigma_{max}}{\sigma_{ult}}(1 - \frac{\sigma_{min}}{\sigma_{max}}) = S_{max}(1-R)$$

$$\sigma_{max} = S_{max}\sigma_{ult}$$

$$\sigma_{amp} = S_{amp}\sigma_{ult} = S_{max}(1-R)\sigma_{ult}$$

$$\sigma_{max}\sigma_{amp} = S_{max}{}^2(1-R)\sigma_{ult}{}^2$$

Substituting σ_{max} and σ_{amp} into (3) and then simplifying, the equation becomes

$$\frac{dD}{dN} = C\frac{(S_{max}{}^2(1-R))^m}{(1-D)^n} \tag{4}$$

where $S_{max} \leq 1$ and $C = \hat{C}\,(\sigma_{ult})^{2m}$

Integrating (4) and substituting the initial condition ($D = 0$ when $N = 0$) we obtain

$$\frac{1}{n+1}-\frac{(1-D)^{n+1}}{n+1}=C(S_{max}{}^{2}(1-R))^{m}N \tag{5}$$

where $0 \leq D \leq 1$.

When the number of loading cycles approaches the maximum number of life cycles, N_f, D approaches 1. Under this condition, (5) becomes

$$\frac{1}{n+1}=C(S_{max}{}^{2}(1-R))^{m}N_f \tag{6}$$

This equation can also be simply expressed in log-log form as

$$\log S_{max}=a+b\log N_f \tag{7}$$

Determination of Material Constants

The constants m, n, and C in equations (5) and (6) can be obtained from the experimental data. By taking the logarithm on both sides of (6), we obtain:

$$-\log(n+1)=\log C+2m\log S_{max}+m\log(1-R)+\log N_f \tag{8}$$

$$2m\log S_{max}=-\log(n+1)-\log C-m\log(1-R)-\log N_f$$

$$\log S_{max}=-\frac{1}{2m}\log((n+1)C(1-R)^{m})-\frac{1}{2m}\log N_f \tag{9}$$

Therefore, the linear regression slope (-1/2m) of the S_{max} versus N_f plot on the log-log scale can be used to compute the material constant, m.

To determine the value of n, we need to use the solution in an intermediate state with partial damage, D, in equation (5). As evidenced from our experimental data as shown in **Figure 3**, D doesn't increase up to 10^4 loading cycles. Therefore, D is relatively small until the maximum number of life cycles is approached. We can expand the $(1 - D)^{n+1}$ term with a Taylor's series and omit the higher order terms. Accordingly, equation (5) becomes

$$\frac{1}{n+1}\left(1-1+(n+1)D-\frac{(n+1)n}{2!}D^{2}+.......\right)=C(S_{max}{}^{2}(1-R))^{m}N \tag{10}$$

For the same applied load where the residual moduli are measured at two different numbers of cycles, N_1 and N_2, the respective damages, D_1 and D_2, can be derived from equation (10);

$$D_1(1-\frac{n}{2}D_1) = C(S_{max}{}^2(1-R))^m N_1 \tag{11}$$

$$D_2(1-\frac{n}{2}D_2) = C(S_{max}{}^2(1-R))^m N_2 \tag{12}$$

Dividing (11) by (12) and canceling the common terms, we obtain

$$(1-\frac{n}{2}D_1) = \frac{N_1}{N_2}\frac{D_2}{D_1}(1-\frac{n}{2}D_2) = K_{12}(1-\frac{n}{2}D_2) \tag{13}$$

where

$$K_{12} = \frac{N_1}{N_2}\frac{D_2}{D_1} \tag{14}$$

Therefore we obtain constant *n*

$$n = \frac{2(1-K_{12})}{(D_1 - D_2 K_{12})} \tag{15}$$

The remaining parameter, *C*, can then be determined using the plot of the normalized maximum stress versus the number of cycles at failure in equation (6) and the already known values of *m* and *n* (Tang et al., 2000).

Experimental Results and Damage Model Verification

Table 4 summarizes the static mechanical properties of the composite used in this research. It shows a 33% increase of its ultimate strength in the lower temperature range (-30° C) as compared to the value at room temperature and a 24% increase of its flexural modulus. It also shows a 24% decrease of its ultimate strength in the higher temperature range (65.6° C) as compared to the value at room temperature and a 43% decrease of its flexural modulus. Each set of fatigue experiments were carried out at different environmental temperatures at the selected maximum/ultimate load rates until the samples failed. The applied load and the number of cycles at failure were recorded. These data were used to establish the *S-N* curves and to verify the damage fatigue model (6). The data were also employed to determine the value of *a* and *b* in equation (7).

Table 5 shows fatigue life at each *S* ratio and in **Figure 4**, the normalized maximum stress is plotted against the number of cycles at failure on the log-log scale for each set of fatigue data obtained at a different environmental temperature. In this figure, the symbols represent the experimental data and the *S-N* curves are obtained from the linear regression of the data. The square of the linear correlation coefficient (R^2) quantitatively indicates the linear correspondence between the maximum stress and the number of cycles at failure. An R^2 value of 1.0 means a perfect linear relationship between the two

quantities; a value <1.0 means a less exact fit. The R^2 values were found to be 0.90, 0.88 and 0.97 at -30° C, room temperature and 65.6° C, respectively.

The experimental data show that there is a strong linear relationship between S and $\log N_f$. **Figure 4** also reveals that under the same applied stress level, the fatigue life of the composite in the lower temperature range (-30° C) is shorter than that at room temperature, due to the brittle and glassy properties of the matrix polymer in the lower temperature range as compared to that at the glass transition temperature (Yang et al., 2004). The fatigue life of the composite in the higher temperature range (65.6° C) is longer than that at room temperature, due to the ductile property of the matrix polymer. Due to this ductile property, damage growth in the higher temperature range was slowed down as compared to that at the room temperature as shown in **Figure 5**. At the room temperature, the fatigue life of small coupon sample is longer than that of full scale deck board because there is no internal heating during the test as shown in **Figure 2**.

The normalized *S*-*N* curve in **Figure 6** can be used to predict the fatigue life of the composite used in this research. We generate thick dotted lines as linear fits of room temperature and -30° C to get the same m value in the analysis. The adjusted lines are still reasonable to fit the experimental data. To determine the m value, equation (9) is rewritten in a simple linear form ($y = a + bx$).

$$\log S = -\frac{1}{2m}\log((n+1)C(1-R)^m) - \frac{1}{2m}\log N_f \tag{16}$$

where

$$a = -\frac{1}{2m}\log((n+1)C(1-R)^m)$$
$$b = -\frac{1}{2m}$$

The values of a and b are obtained from the separate fatigue experimental data obtained at 10-Hz at each environmental temperature and $m = -1/2b$. **Table 6** lists these values and their standard errors for each environmental temperature.

When the values of a and b are substituted into equation (16), the *S*-*N* curve for the composite may be expressed as follows:

$$\log(S^{2m}N_f) = 2am$$

$$S^{2m}N_f = 10^{2am}$$

N_f can be expressed as a function of the S ratio:

$$N_f = \left(\frac{10^a}{S}\right)^{2m} \tag{17}$$

In case of the temperatures -30° C, 21.1° C and 65.6° C, this equation can be expressed as

$S^{15.83}N_f = 0.48$ $\quad N_f = (0.95/S)^{15.83}$,

$S^{15.83}N_f = 94.85$ $\quad N_f = (1.33/S)^{15.83}$ and

$S^{15.83}N_f = 708.39$ $\quad N_f = (1.51/S)^{15.83}$, respectively.

To calculate damage growth, the value of n is determined from the partial damage data which is shown in **Figure 7** at different numbers of loading cycles under a given maximum load by intermittent static test. This figure shows that when the damage becomes substantial, it increases at a constant slope but we may not accurately catch the number of cycles where the substantial damage starts because we only measure the partial damage at the beginning of each order of magnitude (10^3, 10^4, 10^5 *etc*.). This figure also shows that the damage growth within an order of magnitude of loading cycles (dD / $d\log N$) is constant approximately 0.11, therefore, for a given maximum applied load with two partial damages D_1 and D_2 measured at two respective numbers of loading cycles N_1 and N_2, we can obtain
N_2 / N_1 = 10

$$\frac{dD}{d\log N} = \frac{D_2 - D_1}{\log N_2 - \log N_1} = \frac{D_2 - D_1}{\log \frac{N_2}{N_1}} = D_2 - D_1 = 0.11$$

From **Figure 7**, D_1 starts from approximately 0.01 ~ 0.05, therefore,

$$\frac{D_2}{D_1} = \frac{D_1 + 0.11}{D_1} = 1 + \frac{0.11}{D_1} \quad , \quad 3.20 \le \frac{D_2}{D_1} \le 12$$

From (14), we may have

$$K_{12} = \frac{N_1}{N_2}\frac{D_2}{D_1} \quad , \quad 0.32 \le K_{12} \le 1.20$$

Meanwhile, from (4), n must be $\geq$ 1

$$n = \frac{2(1 - K_{12})}{(D_1 - D_2 K_{12})} \ge 1 \tag{18}$$

$$2-2K_{12} \geq D_1 - D_2K_{12}$$

$$D_2K_{12} - 2K_{12} \geq D_1 - 2$$

$$K_{12}(D_2-2) \geq D_1 - 2$$

$$K_{12} \geq \frac{D_1-2}{D_2-2} \quad , \quad \frac{D_1-2}{D_2-2} = \frac{D_1-2}{D_1+0.11-2} \approx 1.06 \quad , \quad K_{12} \geq 1.06 \tag{19}$$

We may have

$$1.06 \leq K_{12} \leq 1.20 \tag{20}$$

$$n = \frac{2(1-K_{12})}{(D_1-D_2K_{12})} \approx \frac{2(K_{12}-1)}{K_{12}(D_2-D_1)} = \frac{2(K_{12}-1)}{0.11K_{12}} \tag{21}$$

Therefore we can obtain

$$1.01 \leq n \leq 3.03 \quad , \quad n = 2 \text{ or } 3 \tag{22}$$

According to the previous research, smaller *n* value might be better to represent damage growth curve, so we select $n = 2$ (Tang et al., 2000).

We can also obtain *C* from given *m*, *n* values. **Table 7** lists these values for each environmental temperature.

Meanwhile, *C* as a function of temperature may be written

$$C = C_1 + \frac{C_2}{T} \tag{23}$$

where C_1 and C_2 = constants and T = temperature.

Substituting *C* into (5) and (6), we can obtain (24) and (25)

$$\frac{1}{n+1} - \frac{(1-D)^{n+1}}{n+1} = C(S_{max}{}^2(1-R))^m N \tag{5}$$

$$\frac{1}{n+1} = C(S_{max}{}^2(1-R))^m N_f \tag{6}$$

$$\frac{1}{n+1} - \frac{(1-D)^{n+1}}{n+1} = (C_1 + \frac{C_2}{T})(S_{max}{}^2(1-R))^m N \tag{24}$$

$$\frac{1}{n+1} = (C_1 + \frac{C_2}{T})(S_{max}{}^2(1-R))^m N_f \qquad (25)$$

To determine the C_1 and C_2, we rely on experimental data at two different temperatures (21.1 and 65.6° C). **Figure 6** displays the linear-fit lines at different temperatures. The *S-N* line for -30° C is far below that for higher temperature. It appears that for a given S (maximum applied load / ultimate load) ratio, the number of cycles at failure for -30° C is less than that for higher temperature due to the brittle and glassy property at the lower temperature region than glass transition temperature of matrix polymer. The strength of the material may have linear relationship at the higher temperature region than glass transition temperature but -30° C may have non-linear relationship as shown in **Figure 8.** The experimental fatigue life might be shorter than calculated value for -30° C.

By taking a logarithm on both sides of equation (25) and substituting the S_{max} and N_f for 21.1 and 65.6° C (294.1 and 338.6° K, where K = absolute temperature), respectively, into the equation, two separate equations for respective 294.1 and 338.6° K can then be subtracted from each other.

$$\log(C_1 + \frac{C_2}{294.1}) - \log(C_1 + \frac{C_2}{338.6}) = 2m(\log S_{max,(338.6)} - \log S_{max,(294.1)}) = 0.87322$$

where $S_{max,(294.1)}$ and $S_{max,(338.6)}$ = the maximum/ultimate stress ratios for 294.1 and 338.6° K, respectively

$$\frac{(C_1 + \frac{C_2}{294.1})}{(C_1 + \frac{C_2}{338.6})} = 7.46827$$

$$(C_1 + \frac{C_2}{294.1}) = 7.46827(C_1 + \frac{C_2}{338.6})$$

$$-0.01866 C_2 = 6.46827 C_1$$

$$\frac{C_2}{C_1} = -347$$

Equations (24) and (25) can then be rewritten

$$\frac{1}{n+1} - \frac{(1-D)^{n+1}}{n+1} = C_1(1 - \frac{347}{T})(S_{max}{}^2(1-R))^m N \qquad (26)$$

$$\frac{1}{n+1} = C_1(1-\frac{347}{T})(S_{max}{}^2(1-R))^m N_f \tag{27}$$

Using the experimental data to determine the material constants and from (27), we have obtained the equation (28) for a wood flour reinforced polypropylene composite

$$S^{15.83} N_f = \frac{-17.06}{1-\frac{347}{T}} \tag{28}$$

where S_{max} = normalized stress to respective static ultimate strength. **Figure 9** shows the predicted and experimental values for fatigue life at different environmental temperatures.

Due to the brittle and glassy property at the lower temperature region, the experimental fatigue life is shorter than calculated value for -30° C. We suggest that the model calculated in this research can be used in upper temperature range from glass transition temperature of matrix polymer.

From (26), the residual modulus for a given maximum applied load after N loading cycles may be predicted

$$E = E_0 \left(1 + \frac{S^{15.83} N(1-\frac{347}{T})}{17.06} \right)^{\frac{1}{n+1}} \tag{29}$$

$$D = 1 - \frac{E}{E_0} = 1 - \left(1 + \frac{S^{15.83} N(1-\frac{347}{T})}{17.06} \right)^{\frac{1}{n+1}} \tag{30}$$

Figure 10 and **11** show the predicted and experimental data for residual modulus and partial damage of the composite using intermittent static test data. The experimental data generated from the intermittent static modulus test is in good agreement with the calculated model.

Conclusions

A fatigue model based on the cumulative damage with cyclic loading is verified with experimental data for a wood flour reinforced polypropylene composite.

Under the same applied stress level, the fatigue life of the composite in the lower temperature range is shorter than that at room temperature, due to the brittle and glassy properties of the matrix polymer and the fatigue life in the higher temperature range is longer than that at room temperature, due to the ductile property of the matrix polymer.

Due to this, damage growth in the higher temperature range was slowed down as compared to that at the lower temperature range.

The strength of the material may have linear relationship at the higher temperature region than glass transition temperature but -30° C may have non-linear relationship so that we would like to suggest that the model calculated in this research can be used in upper temperature range from glass transition temperature of matrix polymer.

To calculate damage growth, partial damage data at different numbers of loading cycles by intermittent static test was used. The experimental data generated from the intermittent static modulus test is in good agreement with the calculated model.

This model can be used to predict the fatigue life of a wood flour filled polypropylene composite at an applied load and to predict the residual modulus and damage growth after a number of cycles at a given load in various structural deck boards and pedestrian bridges.

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Tables

Table 1. Product details and quantities for extruded materials

Material	Quantities	Manufacturer	Product
PP	33.8%	Solvay	HB9200
Wood flour	58.8%	American Wood Fibers	#6020
Talc	4.0%	Luzenac	Nicron 403
MAPP	2.3%	Honeywell	950P
Lubricant	1.0%	Honeywell	OP100

Table 2. Extruder temperature profile utilized for all of the materials produced

	Temperature (˚F)
Barrel Zone 1	370
2	370
3	365
4	360
Screw	360
Die Zone 1	360
2	365
3	370

Table 3. Stresses applied in each fatigue test

Temperature	Maximum Stress (psi)	Ultimate MOR (psi)	S ratio ($\sigma_{max}/\sigma_{ult}$)
-30° C	4,061	6,768	0.60
	4,399	6,768	0.65
	4,738	6,768	0.70
	5,076	6,768	0.75
	5,414	6,768	0.80
21.1° C	2,298	5,106	0.45
	2,553	5,106	0.50
	2,808	5,106	0.55
	3,064	5,106	0.60
	3,319	5,106	0.65
	3,574	5,106	0.70
	3,830	5,106	0.75
	4,085	5,106	0.80
65.6° C	2,715	3,879	0.70
	2,909	3,879	0.75
	3,103	3,879	0.80
	3,297	3,879	0.85
	3,491	3,879	0.90

Table 4. Static mechanical properties of the composite

	Full-scale deck board	Small coupon sample		
Test temperature	21.1 ℃	-30 ℃	21.1 ℃	65.6 ℃
MOR (psi)	7,118	6,768	5,106	3,879
MOE (psi)	756,527	595,310	480,242	271,986
Displacement at break (in)	0.64	0.10	0.13	0.21
Strain at break (in/in)	0.01	0.01	0.01	0.02

Table 5. Fatigue test data for each environmental temperature

	Wood-PP-MAPP								
Freq.	-22 °F (-30℃)			70 °F (21.1℃)			150 °F (65.6℃)		
	R-ratio	S	Fatigue life	R-ratio	S	Fatigue life	R-ratio	S	Fatigue life
10-Hz	0.13	0.45	82,525						
	0.14	0.47	46,879						
	0.13	0.45	30,391						
	0.14	0.45	16,025						
	0.12	0.52	8,789						
	0.12	0.52	2,269						
	0.10	0.50	10,970						
	0.11	0.56	8,760						
	0.10	0.54	37,117						
	0.14	0.55	6,921						
	0.14	0.54	2,011						
	0.10	0.54	4,453						
	0.11	0.58	892	0.09	0.60	161,115	0.16	0.70	126,057
	0.11	0.61	452	0.13	0.58	516,843	0.13	0.70	189,858
	0.09	0.61	1,437	0.13	0.60	373,534	0.15	0.71	164,778
	0.11	0.60	1,613	0.11	0.61	129,360			
	0.19	0.65	909	0.15	0.64	85,450	0.15	0.74	69,802
	0.18	0.65	625	0.11	0.64	68,919	0.12	0.75	76,116
	0.11	0.65	436	0.12	0.63	95,530	0.12	0.75	60,257
	0.12	0.69	580	0.15	0.72	26,887	0.12	0.77	69,514
	0.12	0.69	351	0.15	0.71	15,953	0.14	0.81	17,901
	0.10	0.70	152	0.13	0.70	40,010	0.14	0.80	19,121
	0.11	0.71	289						
	0.15	0.71	90						
	0.10	0.75	159	0.10	0.76	5,312	0.11	0.86	10,120
	0.10	0.75	83	0.13	0.74	6,532	0.13	0.86	7,034
	0.10	0.74	120	0.10	0.74	39,722	0.14	0.85	11,778
				0.10	0.75	8,568			
				0.10	0.75	2,421			
	0.10	0.79	68	0.10	0.80	1,582	0.15	0.91	2,394
	0.10	0.79	44	0.10	0.81	770	0.16	0.92	2,448
	0.10	0.79	40	0.09	0.80	5,429	0.13	0.95	2,141
				0.09	0.80	5,468			
				0.11	0.79	1,165			
				0.10	0.79	1,294			

Table 6. Linear constants and *m* values for each environmental temperature

Temperature	*a*	Standard error	*b*	Standard error	*m*	Standard error
-30 ℃	-0.020	0.016	-0.063	0.005	7.914	0.605
21.1 ℃	0.125	0.026	-0.063	0.006	7.914	0.729
65.6 ℃	0.180	0.013	-0.063	0.003	7.914	0.363

Table 7. Material constants *m*, *n* and *C* values for each environmental temperature

Temperature	*m*	*n*	*C*
-30 ℃	7.914	2	1.595
21.1 ℃	7.914	2	0.008
65.6 ℃	7.914	2	0.001

Figures

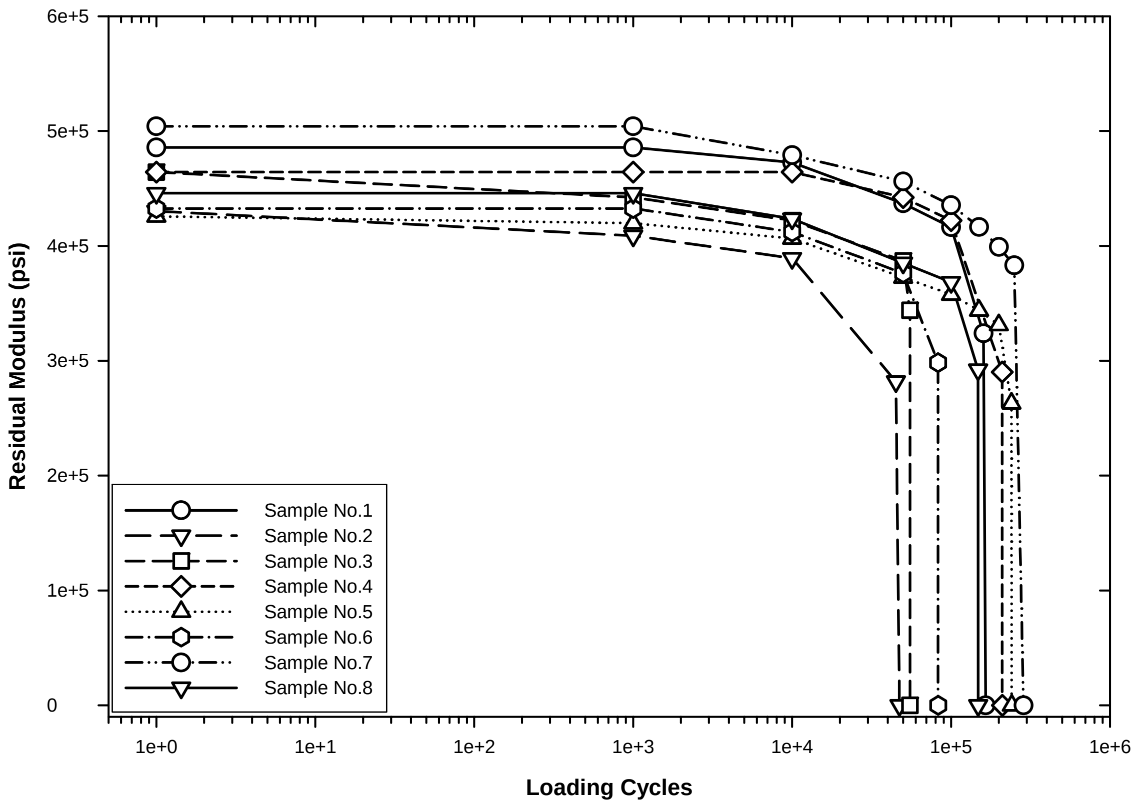

Figure 1. Residual modulus at 10-Hz and 65% of ultimate load.

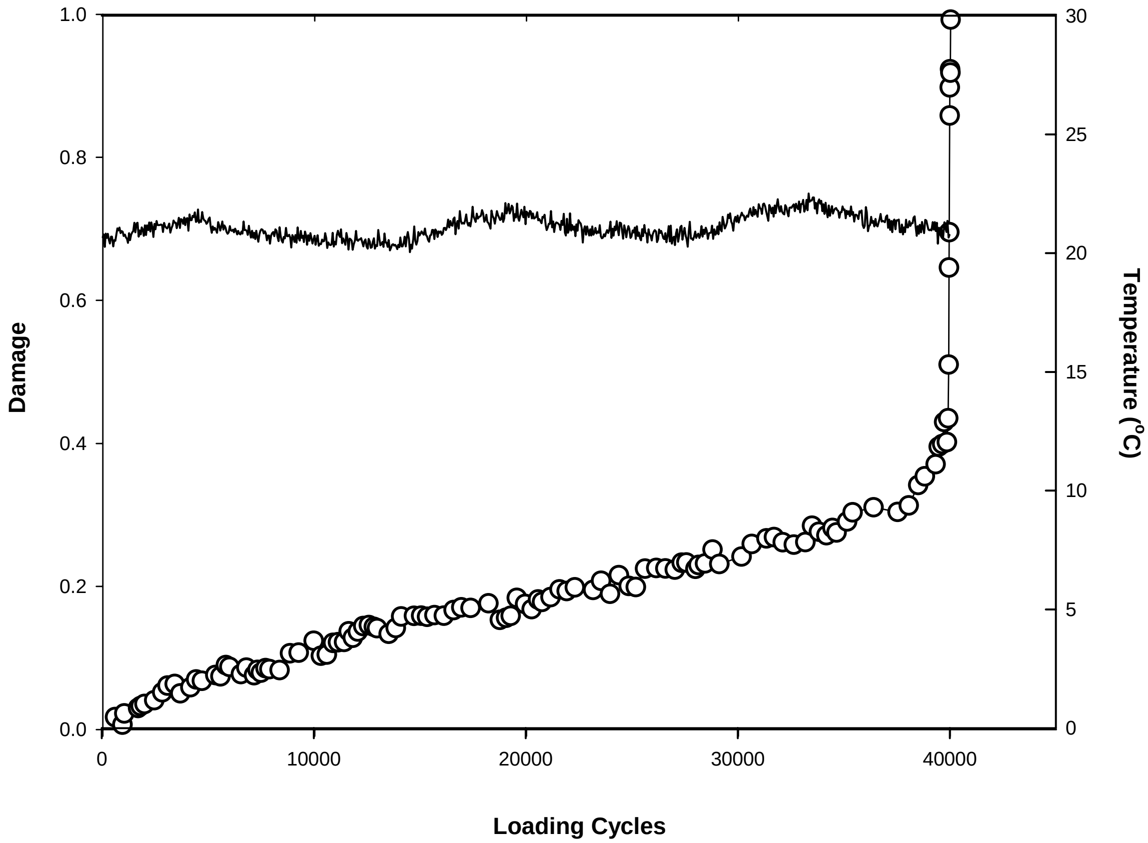

Figure 2. Cumulative damage versus number of cycles at 70% of ultimate load.

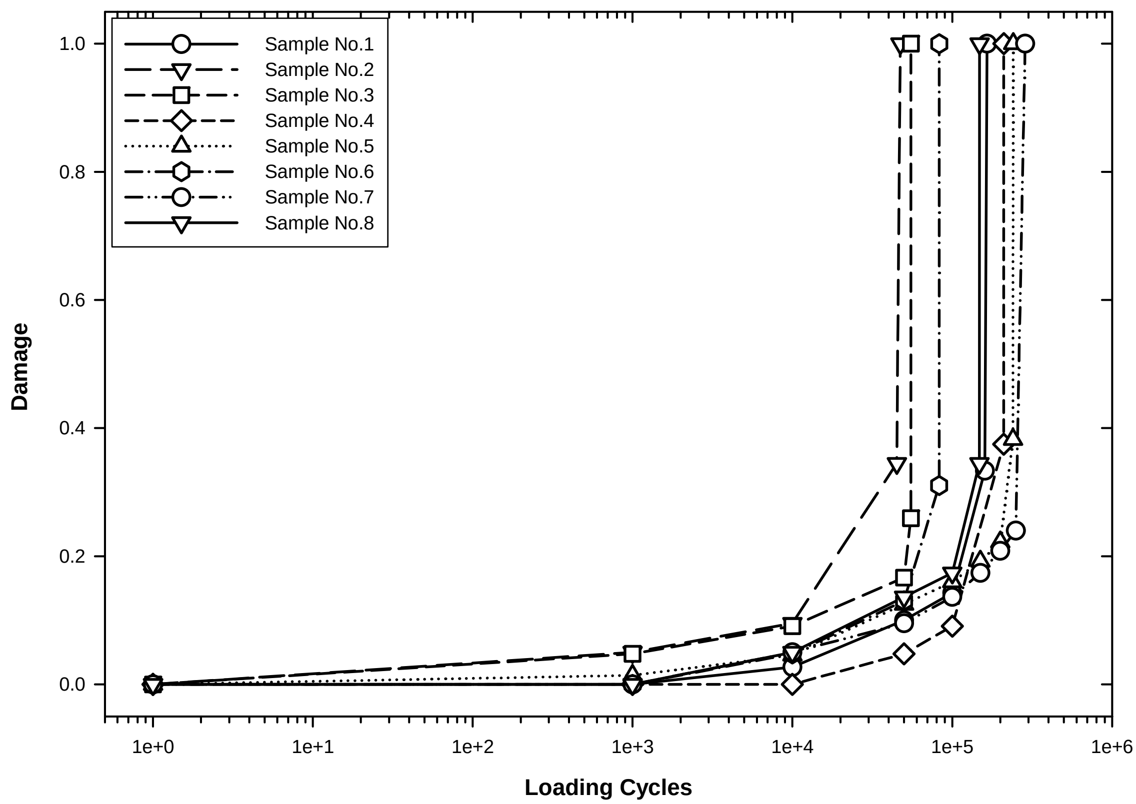

Figure 3. Partial damage at 10-Hz and 65% of ultimate load.

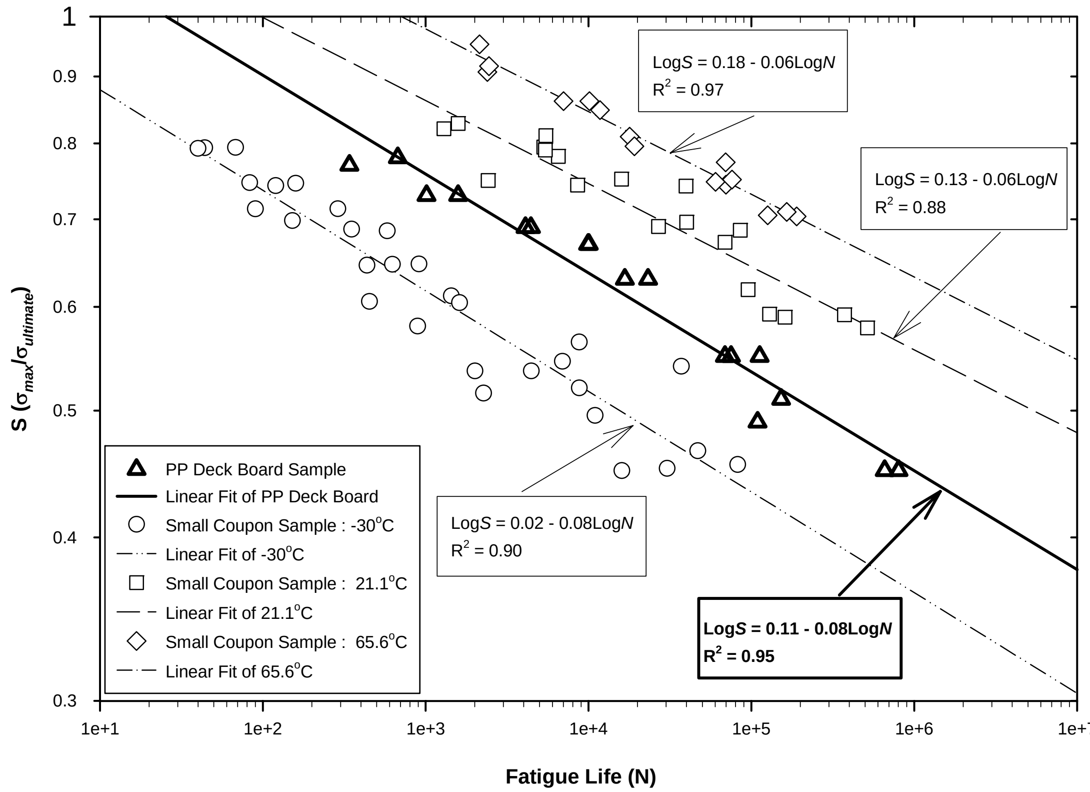

Figure 4. Fatigue life at 10-Hz for each environmental temperature. (log-log scale)

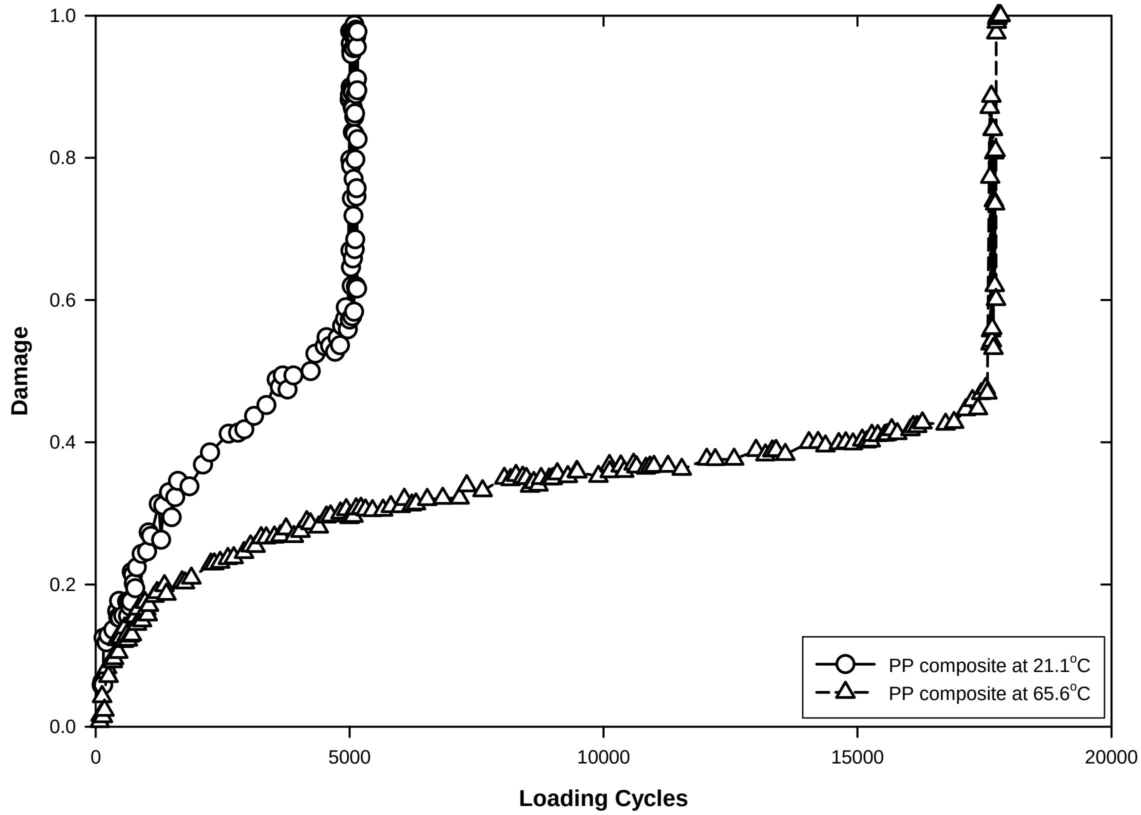

Figure 5. Comparison of damage growth versus number of cycles at 80% of ultimate load between 21.1 and 65.6° C of environmental temperature.

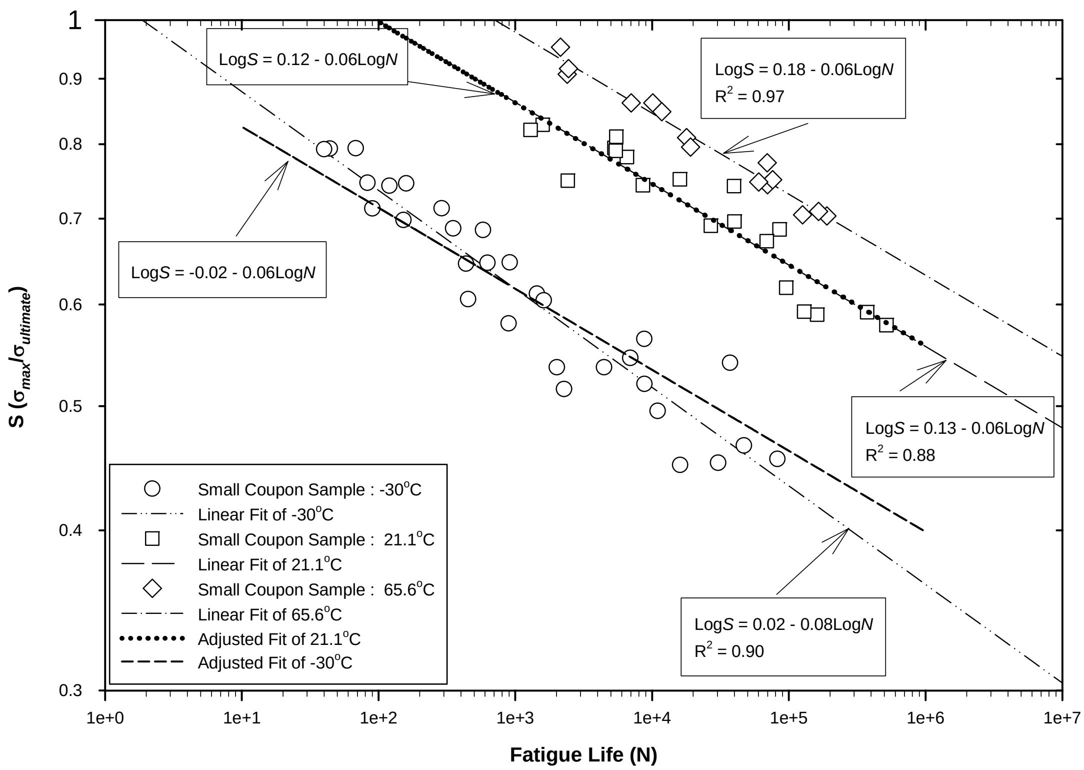

Figure 6. The normalized *S-N* curve and adjusted fit line for each environmental temperature.

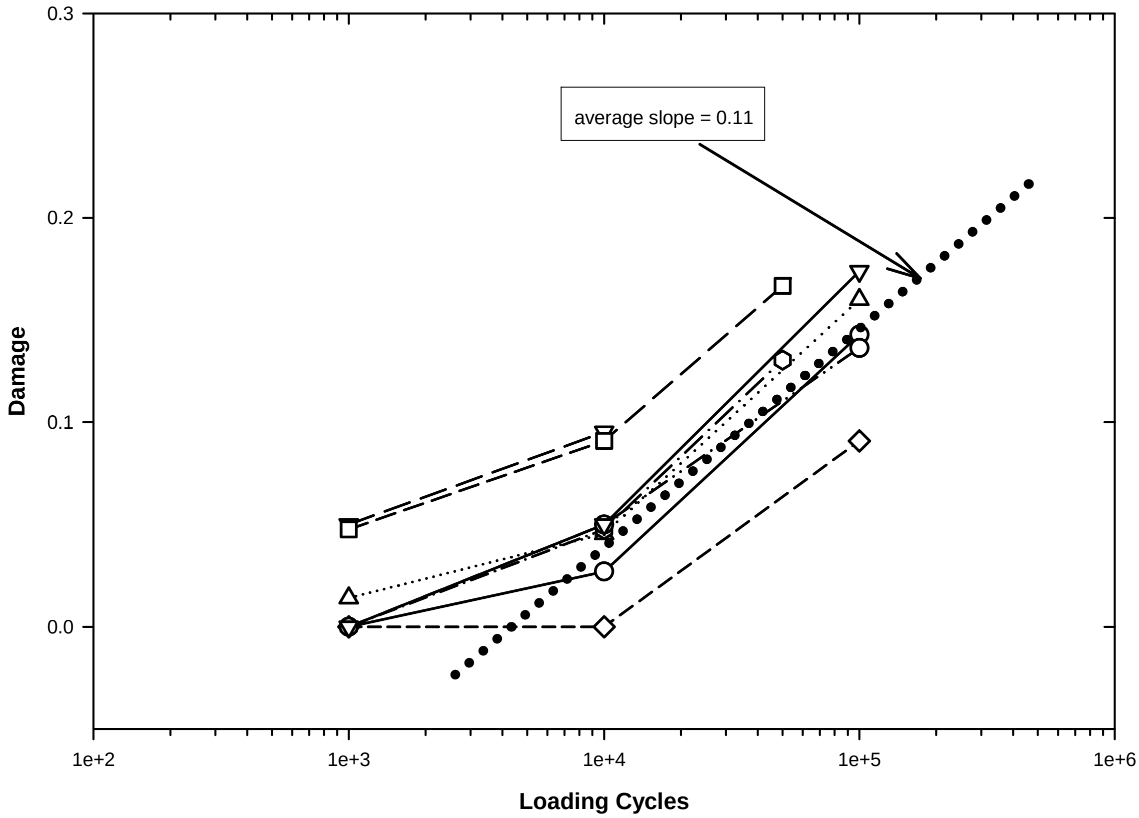

Figure 7. Partial damage at selected loading cycles and 65% of ultimate load.

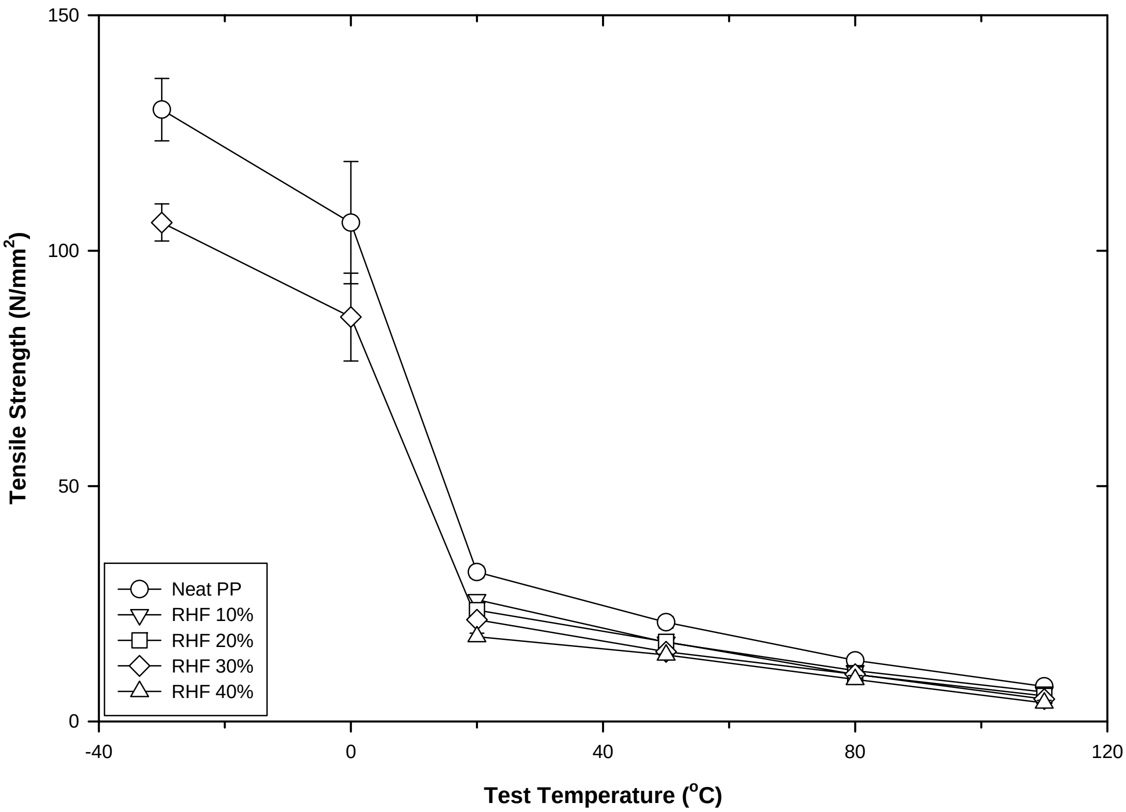

Figure 8. Ultimate tensile strength of lignocellulosic filler (rice-husk flour) filled polypropylene composite at different temperature. (Courtesy of reference [22] Composite Structures, 2004, 63(3-4): 305-312)

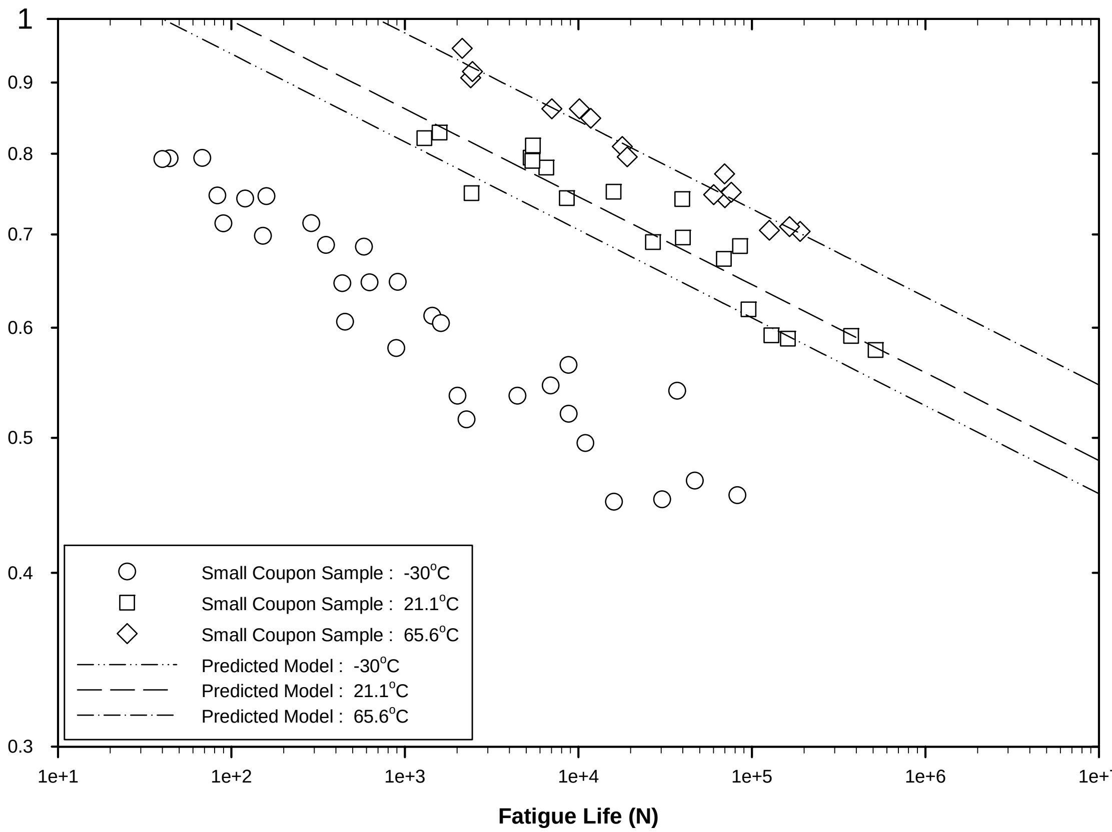

Figure 9. Predicted and experimental values for fatigue life at different environmental temperatures.

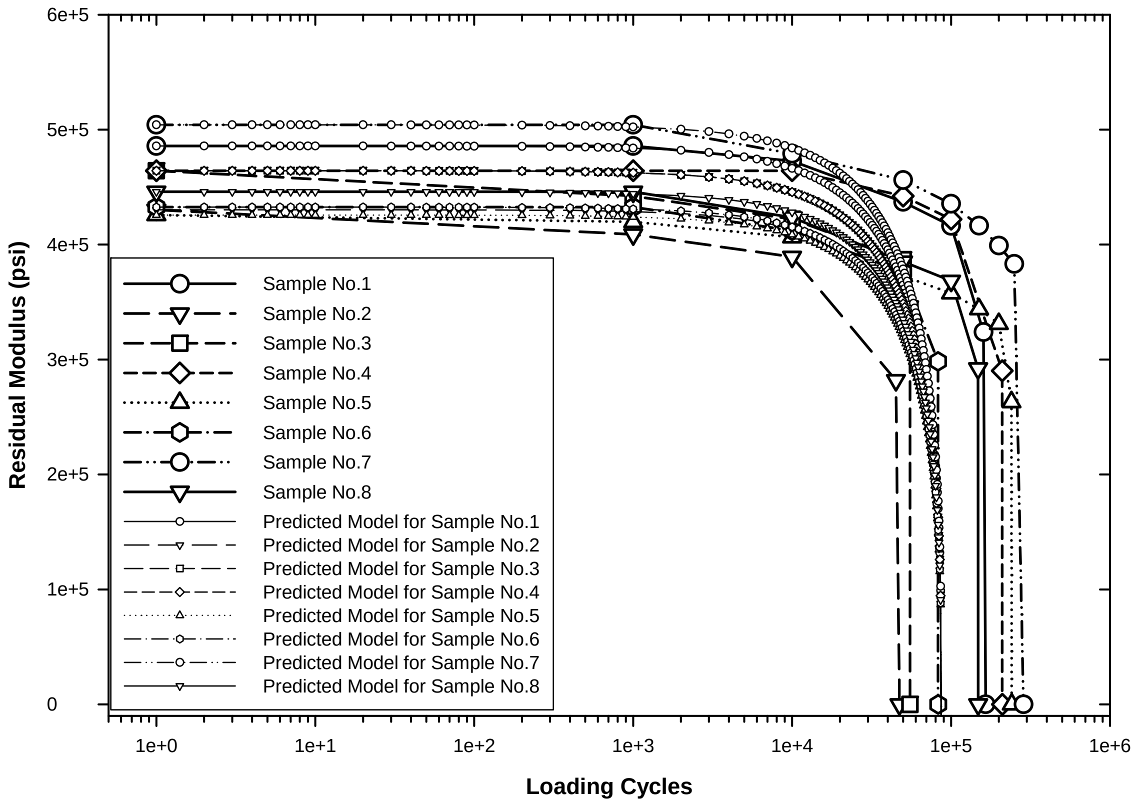

Figure 10. Predicted and experimental values for residual modulus of the composite at 65% of ultimate load.

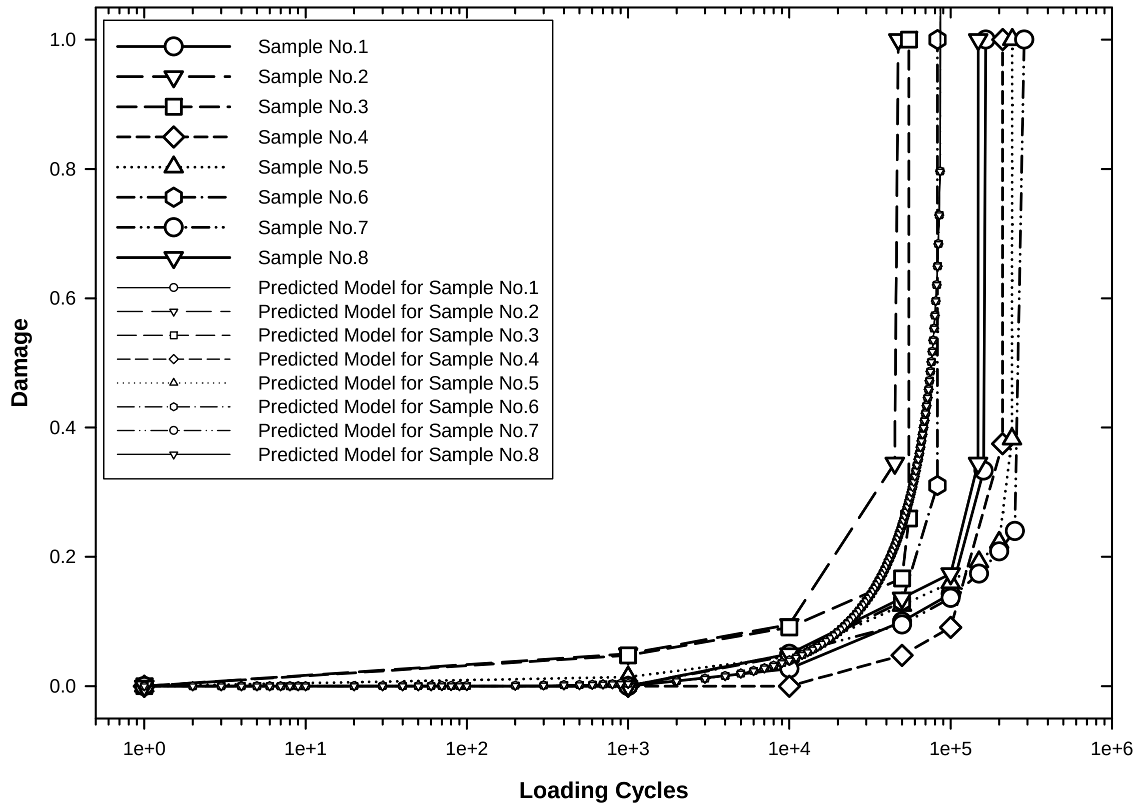

Figure 11. Predicted and experimental values for partial damage of the composite at 65% of ultimate load.

Durable Wood Composites for Naval Low-Rise Buildings

Competitive Environment for Lateral Loading Solutions in the Light Frame Construction Market

Integrated Sill Plate Rim Board Elements

Task C1 – Examine the commercial solutions currently available for resisting lateral loads in the light-frame construction and provide a market assessment of the competitive landscape for these solutions.

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Abstract

Previous research has identified potential for a modified and well-designed structural wood-plastic composite (WPC) for use in sill plate/rim joist systems to address lateral load issues in light frame structures, particularly as they relate to shear forces. WPCs also have the prospect to integrate the fastening system of a sill plate/rim joist into design of the product, which can alleviate significant problems arising from improper installation of hold-downs and anchor bolts in foundation-to-wall applications. The objective of this research was to survey the engineer/designer and residential homebuilder market segments in order to identify market opportunities for WPCs in sill plate/rim joist applications, as well as to identify problems that participants within these two market segments perceive exist in current sill plate applications. Two separate surveys were conducted: [1] a telephone survey was conducted with engineers and designers of light frame structures that primarily operate in seismic-active localities of the United States, and [2] a mail survey was conducted with residential homebuilders that construct light frame wood structures in seismic active regions of the United States. Results indicate that significant problems related to installation exist in the connection of wall systems (i.e., sill plates), as perceived by both engineers/designers and residential homebuilders. An integrated wood plastic solution was neither perceived favorably nor unfavorably by either market segment. Residential homebuilders, however, indicated that product availability and the ability to use and install the WPC sill plate in a similar fashion as current products in the marketplace was important. Survey results favorably suggest that a market opportunity exists for a WPC solution in sill plate applications for light frame structures. However, the WPC solution will have to address issues related to it use and installation, especially among residential homebuilders, in order to be successfully introduced into the marketplace.

Introduction

The US Navy spends approximately 40 percent of its annual budget on its structures, of which the majority of these structures are low-rise wood-based structures. Research has identified that the high moisture associated with coastal communities as being the primary culprit for structure deterioration, thereby leading to substantial maintenance costs (e.g., Foliente et al. 2002, Mankowski and Morrell 2000, Scheffer and Moses 1993). Structures typically begin degrade at the exterior components of siding and trim. Interior building components soon follow, leading to a compromise of the building's structural integrity. Also, recent state and municipal building code mandates have called for improved wall-foundation connections that increase load capacity and provide better moisture resistance.

Based on the previous work conducted for the US Navy, 65 Navy-Marine Corps Liaison Officers provided 89 points of contact (POC) representing Public Works and Resident Officer in Charge of Construction individuals.[1] These 89 POCs at Naval facilities are the individuals involved in the selection and purchase of building materials. In addition, primary data was also acquired from two additional populations: [1] 85 "Prime" Contractors (those contractors who have been involved in Navy construction projects in the past 3 years); and [2] the largest 200 US builders.

[1] Naval Advanced Wood Composites; Contract N00014-00-C-0488

From a technical product perspective, the abovementioned US Navy research identified potential opportunities for WPC technologies in the development of modified oriented strand board/lumber (OSB/OSL) products for use in light-framing structural components. Specifically, this earlier work found potential for modified and well-designed structural WPC in sill plate/rim joist systems to increase wall stiffness to address lateral loads, particularly as they relate to shear. Currently, light construction building design codes are scrambling to address the critical earthquake and wind event concerns with systematic solutions.

Recent advances in material science have lead to the emerging technology of wood plastic composite (WPC) materials. Materials engineers are creating WPC formulations that show promise for structural applications in light frame wood structures. One such product that has the possibility of fulfilling a US Navy need is the WPC sill plate. Wood imparts stiffness to the WPC matrix which improves strength properties. Thermoplastics are hydrophobic and thus provide exceptional resistance to water. Together, wood and plastic show great promise for resistance to moisture and biological decay.

In the process of developing a WPC sill plate solution, an assessment of the general light frame structures industry was undertaken to estimate potential market acceptance of such a product and to assess opportunities for in designing and meeting needs within the marketplace. After a segmentation analysis exercise examining the light frame structures industry, it was found that the industry consists of two significant market segments that would benefit from this research. These segments include design/engineering firms that specify the use of materials in light frame structure applications and the residential construction industry that is located in high seismic areas in the United States. This report focuses on market research aimed directly at these two market segments with regard to their potential to adopt WPC integrated sill plate applications, as well identifying opportunities that may exist within these two market segments for the development of such a WPC product.

The market research collected and analyzed in this study provides strategic market information regarding product/market applications and potential technological solutions for lateral loading applications in light-frame construction. Information resulting from the this study is essential for the development of a strategic marketing plan that can be used to effectively and efficiently design and introduce a new WPC building material, system, and/or technology for lateral loading applications into the light-frame construction market.

Objective

The object of this study was too specifically:

1. Assess the knowledge, perception, and needs of the engineer/ designer in the lateral load solution market, and
2. Uncover market opportunities for potential WPC solutions in the light frame construction market (i.e., residential construction market in the United States).

Out puts generated from this study include:

- An understanding of the issues encountered by engineers and designers as they apply to the lateral loading of light frame structure
- an understanding of the distribution structure for engineered light frame materials,
- identification of current promotional elements for engineered light frame materials,
- identification of some communication mix methods used within engineer/designer and residential homebuilder markets to educate designers and users about lateral loading issues and solutions, and
- market entry strategies for new innovative WPC materials designed for lateral loading applications in light frame construction.

As previously indicated, this research is decomposed into two components. The first component assesses the engineer/designer (i.e., specifiers of product), while the second component assesses the residential homebuilder market (i.e., installers/users of product). Rather than intermingle the assessment of each of these two sample groups, this technical report separates the methods and results for each sample group and then proceeds to conclusions that address perceptions of both groups and the market opportunities that appear to exist for WPC lateral loading solutions.

Methods

Sample Frame for Engineers and Designers Study

Engineers and designers are often the specifiers of materials used in the construction of both commercial and residential light frame structures. After review and examination of the design and engineering aspects of light frame structures, it was discovered that the segment could be divided into two subgroups based on structure design. The first group of structures represents those that are not technically engineered and are simply constructed according to a local or regional prescriptive code. Within this group, all elements of the structure are specified according to predetermined structural data respective to a defined area; the use of an engineer to design the structure is not necessary or required by regulatory code. The code rules contain the prescriptive requirements and outline the minimum engineering and design requirements for structures. For example, the prescriptive code requires a minimum number of nails along the edge of a sheet of oriented strandboard that is used as sheathing based upon the seismic designation of a given area. The second group of structures is represented by those that contain specific engineered elements of the structure or the structure may be entirely engineered. Structural, civil, or professional engineers and designers determine the loads a structure will be potentially subjected to and then specify the structure accordingly to withstand those loads with the addition of a predefined safety factor. This segment of this present study specifically examines engineers and designers within the light frame construction industry. Engineers mainly focus on the engineered segment of the industry; however, their expertise and experience are useful for understanding both segments in the industry.

Given the technical nature of the questions necessary to assess the engineer and designer group, it was decided that a telephone interview survey would be used to collect data (Dillman 1978). In order to obtain statistically valid results, a total of sixty respondents were deemed necessary given the telephone interview method (Cochran 1977). The sample frame of engineers

and designers was drawn from seismic active areas within the United States, mostly being located in the west coast states, Hawaii, and Alaska. Engineers and designers based in seismic active areas were chosen since they were believed to be the most knowledgeable with regard to high load requirements and the associated importance of building durability.

The sample frame was determined by crossing International Code Council (ICC) seismic design categories with U.S. Census county population data to arrive at a sampling scheme that represented population sizes of the respective seismic areas. Significant changes to light frame building design codes occur within the D1, D2, and E ICC seismic design category designations. The ICC "International Residential Code Seismic Design Categories – Site Class D" map, prepared by U.S. Geological Survey, with scale 1:15,000,000, was used to determine which counties within the U.S. had any or all of their borders within classes D1, D2, and E. If any part of a county contained a class D1, D2, or E classification, then the county's entire population was included in the sample frame. The total population of the sample frame was then determined to be the sum of all the county populations within the U.S. that contained a D1, D2, or E classification. Even though many states had ICC designated regions of D1, D2, or E, the "west coast group," representing the states of Alaska, California, Hawaii, Oregon, and Washington, was chosen as the population for the survey after an evaluation of building regulations within each state or major municipality was made. In other seismic regions (e.g., Memphis, Tennessee area), appropriate construction representatives were contacted and queried if they built according to their ICC seismic zoning. The "west coast group" of states was determined to be the only region that regularly inspected structures for their respective seismic zoning and consistently evaluated and systematically updated their seismic codes. Once the west coast region was chosen as the area of focus, the seismic-relevant population of each state was divided by the whole west coast population to determine the number of participants to be chosen from each state for the survey. Finally, a list of 300 structural engineers and designers located in the area of survey interest was drawn randomly and purchased from Dun & Bradstreet, a purveyor of industry-related mailing lists.

Sample Frame for Residential Homebuilder Study

In order to improve the understanding of the market needs and opportunities for a commercial WPC sill plate application that resist lateral loads, an assessment was conducted among the residential homebuilder population. Residential homebuilders were chosen to represent the construction segment of light frame structures since they account for a significant majority of the light frame structures that are built in the United States. Residential homebuilders also represent the bulk of the lateral loading component buying *decision makers* within the light frame structures industry. Engineers and designers typically do not specify a particular brand of lateral loading components in the residential homebuilding industry. Generally, the builder chooses the brand of lateral loading component to purchase. This fact of the industry makes residential homebuilders very important in identifying market opportunities for innovative WPC sill plate products.

Five hundred residential homebuilders were drawn from seismic active areas within the United States based on standard sample size determination protocol (Cochran 1977). Residential homebuilders in high seismic areas were chosen since they tend to build to the strictest code

requirements. Residential homebuilders in high seismic areas are assumed to be accustomed to building more durable structures, from a lateral loading perspective. The sample frame was determined by crossing International Code Council (ICC) seismic design categories with U.S. Census county population data. Significant changes to light frame building design codes occur within the D1, D2, and E ICC seismic design category designations. The ICC "International Residential Code Seismic Design Categories – Site Class D" map, prepared by U.S. Geological Survey, with scale 1:15,000,000, was used to determine those counties within the U.S. that had any or all of their borders within classes D1, D2, and E. If any part of a county contained a class D1, D2, or E classification, then the county's entire population was included in the sample frame. The total population of the sample frame was then determined to be the sum of all the county populations within the U.S. that contained a D1, D2, or E classification. Even though many states had ICC designated regions of D1, D2, or E, the "West Coast Group," representing the states of Alaska, California, Hawaii, Oregon, and Washington, was chosen as the target population for the survey given an evaluation of building regulations within each state or major municipality. In the non-west coast regions, building officials were contacted and questioned if light frame structures were built according to ICC seismic zoning. The "West Coast Group" was determined to be the only region that regularly inspected structures for their respective seismic zoning and consistently evaluated their seismic codes. Within the west coast region, the population of each state was divided by the entire west coast population to determine the number of random respondents chosen from each state.

A sample frame of residential homebuilders was obtained from Dun & Bradstreet, a well-known provider of industry mailing lists. A total of 500 residential homebuilders were required for the study and were proportionally sampled based on the population of state. Specifically, the sample frame by state was as follows: 387 California, 55 Washington, 41 Oregon, 11 Alaska, and 6 Hawaii. To be included in the sample frame, the residential homebuilder was required to have constructed three or more homes in 2004. It was presumed that this particular screening requirement would capture only those residential homebuilders that construct homes on a full-time basis (i.e., homebuilding was their primary occupation).

Survey Design and Execution for Engineers and Designers Study

A survey was executed utilizing a telephone interview process that included a pre-developed script that had been pre-tested by several individuals knowledgeable of the subject area, as well as a nationally renowned expert in the area of engineered design for light frame structures. The script for the survey was highly structured and followed typical protocol for telephone surveys (Alreck and Settle 1995). See the Appendix for a representation of the telephone interview script used in this study. A total of sixty engineers were surveyed in the study, proportionally representing the west coast group of states based on population estimates. The survey began with two qualifying questions. The first qualifying question requested that the respondent indicate their employment position to determine if the interviewee was an in fact an engineer and/or designer. The second question asked if the engineer designed or engineered light frame structures. The questionnaire was specifically designed for engineers and designers who had regular work-related experience with light framed structures. Once it was determined that the interviewee was qualified for to complete the telephone interview, the engineer was asked questions that addressed the following issues:

- Durability and code issues with respect to light frame structures
- Construction and installation issues with respect to light frame structures
- Current commercialized product knowledge and use in light frame structures
- Potential products for light frame structure engineered applications
- Information concerning how engineers and designers of light frame structures gather information about products
- Demographic information about the interviewee and their firm

All survey participants were called to arrange a convenient interview time. The vast majority of telephone interviews took approximately thirty minutes to complete. Interviews were completed within a twenty day time window during the summer of 2005.

Survey Design and Execution for Residential Homebuilder Study

A survey was conducted using Dillman's Total Design Method as the framework for survey design and execution (Dillman 1978). The survey questions were developed using extensive input from experts in the fields of residential construction and building codes. A preliminary survey instrument consisting of approximately 30 questions was pretested by several academics with expertise in residential construction techniques, as well as by six residential homebuilders located in California. A final survey instrument consisting of 27 questions ranging from binary response questions to multi-part questions was prepared based on input from pretest participants (see Appendix for a representation of the residential homebuilder mail survey).

The homebuilder survey took place in the late spring of 2006. Specifically, the initial wave of survey was mailed, utilizing first class postage, in late March of 2006. Participants received a packet in the mail consisting of a detailed cover letter explaining the purpose of the survey, an eight-page self-guided questionnaire, and a self-addressed stamped envelope for returning their completed questionnaire. Approximately three weeks after the initial mailing of the survey, a follow-up survey was sent to all participants. This follow-up survey package was identical in all respects to the initial mailing with the exception of the cover letter; the follow-up cover letter in this second wave mailing stressed to a greater degree than the initial cover letter the importance of completing the survey. Finally, when eight weeks had passed from the initial mailing date in March 2006, a third wave of the survey was mailed to all participants (excluding those participants that had returned their survey. The third wave of surveys was mailed using United States Postal Service's Priority Mail service so as to increase the perceived importance of the survey. The use of Priority Mail service as a method of delivery has been reported to increase survey response rates substantially (Moore et al. 2001).

Data Analysis for Engineers and Designers and Residential Homebuilder Studies

Completed survey data from both the engineers and designers survey and the residential homebuilder survey was input into an SPSS statistical datasheet for analysis (SPSS, Inc. 2005). Analysis of data consisted of descriptive statistics, such as means, frequencies, and correlations, as well as univariate and multivariate statistics.

Results of Engineer and Designer Survey

A total of 60 engineers and designers were identified for participation in this study after directly contact had been made with approximately 140 potential participants. Several engineers and designers were determined not to be viable prospects for the study since they had little to no experience in designing light frame structures. In addition, a small handful (less than 10) of engineers and designers that did indicate experience with designing light frame structures indicated that they did not have the time to participate in a telephone survey interview (i.e., survey refusals). Encouragingly, the vast majority of engineers and designers with experience in the design and specification of light frame structures agreed to participate in the study. After agreeing to participate, a later date/time was scheduled with the engineer/designer to conduct the telephone interview. Given the small number of refusals to participate in the study, it is believed that the data and statistics reported herein are representative of the engineer and designer population located in the states of interest.

The sixty participating engineers and designers had a mean of just over 25.4 years of experience in engineering or designing light frame structures; however, the range of years of experience differed substantially from as little as four years to as much as 65 years.

Durability and Code Issues in Light Frame Structures

Survey participants were asked to identify the connections in light frame structures that they perceived to be weakest and strongest with respect to the application of a load. Results indicated that the roof to shear wall connection was perceived as being the weakest connection in light frame structures that were built to code requirements (Table 1). Note that one-third of the survey participants identified a specific structural connection involving the sill plate of the structure as being the weakest structural connection. Engineers and designers perceived that the strongest structural connection in light frame structures was the sill to foundation connection (Table 1).

Table 1. Weakest structural connections in light frame structures as perceived by engineers and designers.

	Connection Perceived to be	
Connection	Weakest (n = 59)	Strongest (n = 59)
Roof to shear wall	18	6
Shear wall to sill	11	2
Sill to foundation	5	18
Internal shear wall strength	3	13
Sill plate bearing capacity	4	5
All could perform equally	18	15

Survey participants were also asked to indicate their preference of the design and application of a sill plate for light frame structures. Respondents overwhelmingly believed that a *3x* sill plate was the best alternative to a *2x* sill plate with twice as many anchor bolts, as well as alternative simply described as “another type of sill plate system” (Table 2). Along this same line, the study

revealed that acceptance of *3x* lumber at panel joints has been almost universally accepted by engineers. Only two out of 60 study participants (about 3 percent) of the engineers and designers did not agree with the requirement of *3x*'s at panel joints.

Table 2. Sill design preference for light frame structures among engineers and designers.

Sill Design	Percent of Respondents Indicating Design Preference (n = 58)
3x or thicker sill	86.2
2x sill with twice as many anchors	8.6
Another type of sill system	5.2

To understand the perceived adequacy of building codes as they relate to lateral forces in light frame structures, survey participants were specifically asked: "Are there any problems/issues related to current code as it relates to lateral forces in light frame construction. Results indicate that more than one-half of the engineers and designer believed that problems/issues existed as they pertain to how the current code deals with lateral forces in light frame construction (Table 3).

Table 3. Engineer and designer response to question: "Are there problems/issues related to current code as it relates to lateral forces in light frame construction?"

Do code problems exist with respect to lateral forces?	Percent of Respondents (n = 58)
Yes	55.2
No	29.3
Neutral	15.5

Survey participants were also asked to indicate whether they believed that hold-downs and shear transfer connectors resulted in excessive compression stress on sill plates. This question was asked to gauge whether engineers and designers perceived that these fasteners were being properly installed in light frame construction applications. For the most part, few study participants believed that hold-downs (15.5 percent) or shear transfer connectors (12.1 percent) were resulting in excessive compression stress on the sill plate (Table 4). Asked whether the number of hold-downs currently required by code are adequate in light frame structure applications, more than three-fourths (78.6 percent) of the engineers and designers agreed that they were adequate.

Table 4. Engineer and designer response to question "Are hold-down compression stress and shear transfer connector compression stress excessive [in sill plate applications] given current installation practices in light frame construction?"

	Connector Results in Excessive Compression Stress on Sill Plate (percent of respondents)	
Engineer and Designer Response	Hold-downs (*n* = 57)	Shear Transfer Connector (*n* = 58)
Yes	15.8	12.1
No	84.2	87.9

Construction and Installation issues in Light Frame Structures

Survey participants were also asked to respond to questions concerning current practices among the labor force installing fastener connection in light frame structures. Specifically, engineers and designers were asked to indicate the incidence rate for which they observed improperly installed hold-downs and improper layout of anchor bolts on light frame structure jobs. Results of the survey indicated one-fourth of engineers and designers observed improper hold-down use in 100 percent of jobs they inspected, while nearly the same number observed improper anchor bolt layout in 100 percent of the jobs they observed (Table 5). Eighty percent of respondents indicated that hold-downs were improperly installed on 20 percent or more of the jobs they that observed, while nearly 72 percent of respondents indicated that anchor bolt layouts were incorrect on 20 percent or more of the jobs that they observed. Only one survey participant indicated that they had never observed an improperly installed hold-down, and just two survey participants indicated that they had never observed improperly layout of anchor bolts on a job. In sum, the results reported in Table 5 suggest, assuming engineers and designers are correct in their observations, that the current labor force employed to construct light frame structures in inadequately trained to properly install hold-downs and lack the knowledge to properly layout anchor bolts.

Similarly, participating engineers and designers were asked: "How often do you believe builders properly install *all* lateral loading components in any particular light-framed wood structure job?" More than 25 percent of respondents indicated that on all light frame construction jobs contain improperly installed lateral loading components, while more than 55 percent of respondents indicated that at least one-half of light frame construction jobs exhibit improperly installed lateral loading components.

Table 5. Incidence of improperly installed hold-downs and improper layout of anchor bolts as observed by engineers and designers.

	Incidence of Structural Fastener Application Misuse/Misapplication	
Percent of Jobs	Hold-downs (n = 60)	Anchor Bolt Layout (n = 60)
0 to 19	12	17
20 to 39	18	15
40 to 59	6	9
60 to 79	3	2
80 to 99	6	5
100	15	12

Commercialized Lateral Loading Product Issues in Light Frame Structures

A scale was developed for rating the importance of two variables directly related to commercialized lateral loading solutions in the marketplace. In particular, these variables dealt with the time it takes to install the component and the up-front component price. A scale ranging from 1 to 5, with 1 representing "not at all important" and 5 representing "very important," was used to gauge study participants' response. Results from these two questions indicated that engineers and designers were neutral as to the importance of installation time (mean = 3.4) and up-front price (mean = 3.1) of lateral loading solutions. Note that these results may be reflective of the fact that engineers and designers do not experience the economic cost of purchase and installation of lateral loading solutions. As such, they may be unable to express the importance of these two issues.

A relatively new product to the lateral loading component market is the prefabricated shear wall. A large majority of the engineers and designers (86.4 percent) believed that prefabricated shear walls were an adequate engineered solution for transferring lateral forces within light frame structures. When asked if they had designed a structure using a prefabricated shear wall, slightly more than two-thirds (68.3 percent) of the engineers and designers indicated that they had done so. Approximately one-half of the engineers who indicated that they had specified prefabricated shear walls stated that they had only used *Simpson* brand walls, while the other one-half said they had specified multiple brands of prefabricated shear walls. Out of 29 engineers and designers who stated that they had a prefabricated shear wall preference, 65.5 percent said that preference was for the *Simpson* brand. Likewise, the *Simpson* brand was overwhelming preferred among survey participants for anchor bolts and hold-downs, with a over 96 percent share of the engineers and designers stating that they preferred *Simpson* over other brands available in the marketplace.

Even though the ICC code for light frame structures views oriented strandboard (OSB) and plywood as interchangeable for shear wall construction, 58.3 percent of the engineers said they preferred plywood. In addition, 38.3 percent said they didn't have a sheathing preference, while 3.3 identified OSB as their preferred panel material.

Potential Lateral Loading Solutions for Light Frame Structures

Engineers and designers were asked to rate how familiar they were with [1] the voluntary industry ban of CCA treated wood in residential construction applications, [2] the use of non-corrosive hardware when using second generation treated wood, [3] wood-plastic composites, and [4] engineered wood-plastic composites. The rating scale used for questioning ranged from 1 to 5, with 1 being “not familiar,” 2 “some what familiar,” 3 “familiar,” 4 “very familiar,” and 5 “extremely familiar.” Results displayed in Table 6 provide an indication of the distribution of familiarity scores, as well as the mean score for each of the four areas of study interest.

Nearly two-thirds of the study participants were not familiar with the voluntary industry ban of CCA treated wood in residential construction application; the mean familiarity score for the CCA ban issue was 1.77. Engineers and designers reported being somewhat familiar with non-corrosive hardware (mean = 2.45). Familiarity among engineers and designers for WPCs and engineered WPCs was extremely low, with means of 1.50 and 1.4 respectively. Fifteen percent of engineers and designers were at least familiar with WPCs, and only about eight percent of them were at least familiar with engineered WPCs.

Table 6. Engineer and designer familiarity with CCA treated wood, non-corrosive hardware, WPCs, and engineered WPCs.

	Engineer and Designer Familiarity With . . .			
Familiarity Score	Voluntary CCA Ban (n = 60)	Non-corrosive Hardware (n = 60)	Wood-Plastic Composites (n = 60)	Engineered Wood-Plastic Composites (n = 60)
1 = Not familiar	38	18	41	45
2 = Somewhat familiar	7	16	10	10
3 = Familiar	7	11	7	1
4 = Very familiar	7	11	2	4
5 = Extremely familiar	1	4	0	0
Mean[a]	1.77	2.45	1.50	1.40

[a] Rating scale was as follows: 1 = “definitely,” 2 = “probably,” 3 = “neutral,” 4 = “probably not,” and 5 = “definitely not”

Engineers and designers were also asked during the telephone interview process to provide a rating of whether they would “specify an engineered wood-plastic composite sill plate with comparable design values to treated wood sill plates.” The rating scale used for this question was as follows: 1 = “definitely,” 2 = “probably,” 3 = “neutral,” 4 = “probably not,” and 5 = “definitely not.” Study participants responded with a mean rating of 2.3, which was not found to be significantly different than a neutral response of 3. Slightly less than one-fourth of the respondents indicated they would definitely specify a WPC sill plate, and only eight percent of the respondents responded “probably not” or “definitely not” to specifying a WPC sill plate.

Engineers and designers were evenly split with regard to WPC sill plates that included prefabricated slots for stud placement (50 percent interested and 50 percent uninterested). However, nearly 90 percent of engineers stated they were interested in an integrated modular prefabricated sill plate component.

Engineer and Designer Sources of Product Information

During the telephone interview process, study participants were read a list of eleven sources by which they could potentially acquire information regarding commercially available lateral loading products. First, the participants were asked to respond either "yes" or "no" as to whether they used each respective information source within the last year to acquire information about lateral loading products. If a respondent indicated that they had used a respective method, then they were asked to rate how useful the method was to them using the following five-point Likert-like scale: 1 = "very useful," 3 = "neutral," and 5 = "not at all useful." Respondents results are displayed in Table 7.

More than three-fourths of engineers and designers indicated that they learned about lateral loading solutions from a colleague/associate/partner or from a manufacturer's promotional items. At least one-half of engineers and designers stated that they obtained lateral loading solution information from included manufacturer's websites, trade publications, and manufacturer's agents/representatives. All eleven potential sources of information concerning commercial lateral loading solutions were found to be either very useful or useful.

Table 7. Sources of information to learn about commercial lateral loading solutions that are reportedly used by engineers and designers of light frame structures.

Source of Information	Percent Using Source	Mean Usefulness of Source[a]
Colleague/Associate/Partner	79.6	1.6
Manufacturer's Promotional Items	76.2	1.7
Manufacturer's Website	67.8	1.9
Trade Publication	62.7	2.2
Manufacturer's Agent/Representative	59.3	1.7
Academic Conference	45.8	1.9
Trade Show Seminar	42.4	1.9
Non-manufacturer's Website	37.3	2.0
Press Release	25.4	2.1
Wholesaler	11.9	2.0
Retailer	8.5	2.3

[a] Rating scale was as follows: 1 = "very useful," 3 = "neutral," and 5 = "not at all useful"

Further, engineers were asked if they found samples and demonstrations useful for learning about new lateral loading solutions. Slightly more than 80 percent of the respondents indicated that samples were useful, while 93 percent of engineers found demonstrations useful.

Results of Residential Homebuilder Survey

A total of 166 of 500 mailed homebuilder surveys were returned, of which 81 surveys were complete and usable for analysis purposes. Eighty surveys that were returned were from individuals stating that residential construction was not their primary occupation, while three returned surveys were incomplete to such a degree that they were not useful for analysis. A total

46 surveys were undeliverable. Given these results, the effective sample size for the mail survey was determined to be 374 (i.e., 500 less 80 incorrect industry classifications less 46 undeliverable surveys). Thus, the effective response rate to the homebuilder survey was slightly less than 22 percent, which is about the norm for surveys conducted in the industry.

Slightly more than 28 percent of the usable surveys were returned after the first mailing, while just fewer than 22 percent of the usable surveys were returned as part of the second wave mailing. One-half of the surveys were returned after the third mailing, which was the only wave that utilized USPS Priority Mail service as the delivery method. The Armstrong and Overton (1977) "wave method" was utilized to determine if non-response bias was an issue of concern in this study. This method assumes that late respondents to a survey are representative of non-respondents in their responses to survey questions; thus, late respondents serve as a proxy for non-respondents. In this study, ten randomly selected variables were statistically analyzed by comparing the first 20 percent of usable returned surveys to the last 20 percent received. The response to only one variable out of the ten randomly selected for analysis was found to be statistically different between early and late respondents. Random variation alone can account for one statistical difference between the two groups. Thus, this bias check suggests that non-response bias is not a significant issue of concern in this study.

In order to assess the scale of construction taking place among respondents to this study, survey participants were asked to report their gross revenue for the year 2004. The average gross revenue for responding residential homebuilders was slightly more than $2 million (standard deviation = $4.3 million), which was calculated from 62 of the 81 participants reporting their gross revenue.

Survey participants were also asked to estimate the percentage of the company's gross sales revenues that were generated from constructing various residential structures in 2004. The type of structure that generated the greatest amount of revenue for companies was custom homes, representing two-thirds of all revenues. Wooden light frame commercial structures and other wood light frame structures (e.g., detached garages, pole buildings) each represented approximately 4.5 percent of revenues generated by participating builders in 2004, while tract homes and multi-family dwellings each represented slightly more than 3 percent of revenue generated. Nonwood structures represented about 5 percent of revenues generated and nearly 12 percent of revenue generated was from "other" construction-related activities.

Survey results indicated that participants, on average, operated relatively small companies. The average number of full-time year-round individuals employed at residential construction firms was reported to be 9, while the number of seasonal employee numbered three on average. It should be noted that the distribution of the number employees across responding companies was bimodal; namely, there were many companies with three or fewer full-time employees and several very large companies employing more than 15 to 20 individuals full-time.

Similar to the engineer and designer survey, residential homebuilders in this were asked about how familiar they were with different issues listed in Table 8. Approximately two-thirds of survey respondents stated that they were at least somewhat familiar with the voluntary industry ban of CCA treated wood in residential construction applications. Sixty-one percent of survey

participants to the study expressed at least some level of familiarity with the use of non-corrosive hardware when using second generation wood preservation treatments, such as ACA, ACQ, Cu-HDO, etc. Nearly all survey participants (96.3 percent) indicated at least some the familiarity with WPCs and engineered WPCs, while slightly more than 65 percent of survey participants indicated at least some familiarity with engineered WPCs. The mean familiarity rating across the four issues was highest for WPCs and statistically the equivalent for the remaining three issues.

Figures 1 through 4 provide a breakdown of data reported in Table 8 by plotting the familiarity response category for each of the four issues examined. Only WPCs shows a distribution skewed toward familiarity rather than unfamiliarity. Interestingly, despite their presumed exposure to using treated wood on a regular basis, residential homebuilders in this study were found to lack reasonable familiarity with the industry ban on the use of CCA treated wood in residential applications.

Table 8. Residential homebuilder familiarity with CCA treated wood, non-corrosive hardware, WPCs, and engineered WPCs.

Homebuilders familiarity with . . .	Mean	Standard Deviation	*n*
The voluntary ban of CCA treated wood in residential homes	2.21	1.15	81
The use of non-corrosive hardware with second generation wood treatments, such as ACA, ACQ, Cu-HDO, etc.	2.21	1.18	80
Wood-plastic composite products	3.38	1.02	81
Engineered wood-plastic composite products	2.17	1.13	81

[a] Rating scale was as follows: 1 = “not familiar,” 2 = “somewhat familiar,” 3 = “familiar,” 4 = “very familiar,” and 5 = “extremely familiar”

Residential homebuilders were specifically asked if they believed that there were issues or problems with the current code system concerning lateral loading forces within the conventional construction provisions for light-frame construction. Nearly 30 percent of the respondents answered affirmatively to this question, while 27 percent indicated that there was no problem. Slightly more than 43 percent of the respondents were neutral in their response. If a survey respondent indicated that there was a problem with the current code system, then they were asked to indicate what they perceived to be those issues/problems. Table 9 provides a summary of issues/problems that survey participants identified regarding the current code system concerning lateral forces within the conventional construction provision for light frame construction.

Survey participants were also asked if they would be receptive to an alternative light frame building system that did not require traditional hold-downs, but instead exhibited equivalent or superior capabilities relative to traditional hold-downs. The overwhelming response (97 percent) to this question was that homebuilders would be receptive to an alternative to traditional hold-down technology. The following two responses were two reasons that a few of the respondents indicated why they would not be receptive to an alternative technology: “[there

would be] difficulty in remodel tie-ins and matching existing wall and ceiling lines" and "I like what I'm familiar with."

Table 9. Issue and problems identified by residential homebuilders with regard to current code system concerning lateral forces within the conventional construction provisions for light-frame construction?

Issues/Problem Identified
In California is OK. Structural engineers here are responsible for their design. Florida and hurricane disaster areas are built too weak. It's a burden to the taxpayer.
With wood construction there are an abundance of metal connections. Metal connectors thus do get in the way of other building trades.
Codes are ambiguous and agencies interpretations are different making difficult to design.
No problems with code system, but engineers tend to over-engineer in this area.
We wrap our customs homes completely with ½" OSB and sheet rock garages, etc. My sense is that our houses are much stronger than just the eng, shear areas provide, yet this adds rigidity, but is accounted for.
Code system is written by folks who are great in math, but poor in logic. Too much emphasis on product that a math guy can put a value on and not enough ability to see or calculate a structure as a whole.
Too much *Simpson* hardware [is] required.
Building departments look only at single load structure situations. Reality says total assembled structure absorb loads.
The issue is the increasing expense. We need a solution to workforce housing, something between a double-wide and the *Simpson* dream home. (*Simpson* hardware)
Braced wall details are hot clear, mostly hot needed for high quality fully sheathed houses.
Over-engineered. Engineering based on general geographic area not accounting for special location issues.
Too much hardware.
Way over-engineered. It appears since the [California] Northridge earthquake, the ICBO has paid by *Simpson Co.* to require their product. The single family homes are overkill.
There are too many metal connectors used in construction of light framed construction.
Absence of clear-cut concise requirement that is universally required them out state of Alaska.
Framing members at boundary nailing over drilled sill plates (for anchor bolts).
These issues are in some cases overblown and in others understated.
Wood parts. Most of L.A. B[uilding] codes are strong.
Over build but not for modular homes.
Too many hold downs.
Cannot be specific, however I believe in certain circumstances it may be to[o] stringent.
Houses too rigid.
Consistency among building officials.
Over protection.
Code too limited in option's to accommodate shears.

Survey participants were asked to indicate whether they had certain brand preferences for the hold-downs that they use on their projects. Slightly more than 89 percent of the residential homebuilders indicated that they preferred the *Simpson* brand hold-downs. Approximately 2.5 percent of the respondents indicated that they preferred *USP* brand. Five percent of the respondents indicated that they preferred an unspecified brand, while the remaining respondents indicated that they favored multiple brands of hold-downs. Survey participants were provided a follow-up question asking why they held a certain brand preference. The dominant response was that the brand was readily available in respondent's market.

Survey participants were requested to specify their level of familiarity and use of five commercial shear wall products currently available in the marketplace (Table 10). The responses to this question provided a proxy measure of adoption that residential homebuilders have for the five shear wall products. Results indicate that the majority of the study participants expressed that they use Simpson's *Strong-Wall Shearwall*. Participants revealed that they were fairly familiar with Trus-Joist's *TJ-Shear* Panel and Simplified Structural System's *Hardy Frame*. Respondents were relatively unfamiliar with the remaining two products assessed in the survey. The distribution of responses across the five shear wall products assessed can be viewed in Figure 5.

Table 10. Residential homebuilder familiarity with various commercial shear wall products currently available in the marketplace.

Shear Wall Product	Mean[a]	Standard Deviation	*n*
Simpson's *Strong-Wall Shearwall*	3.67	1.25	80
Trus-Joist's *TJ-Shear* Panel	2.64	1.41	76
Simplified Structural System's *Hardy Frame*	2.33	1.36	76
E Z Tech's *Z-Wall*	1.36	0.82	75
Shear Transfer System's *Shear Max* panel	1.59	1.12	75

[a] Rating scale was as follows: 1 = "My company is not at all familiar with this product," 2 = "My company is familiar with this product, but has never used it," 3 = "My company has used the product, but no longer does," 4 = "My company uses this product from time to time for certain applications, and 5 = "My company prefers this product and uses it whenever possible"

Survey participants were asked to indicate their preference of sheathing material, oriented strandboard (OSB) or plywood, along various product attributes in shear wall applications (Table 11). Just over one-half of the respondents indicated that they believed that plywood was superior to OSB in edge nailing. Nearly 53 percent of the study participants expressed that plywood is superior to OSB in nailing holding. With regard to consistent quality, 61 percent of respondents indicated that OSB was superior to plywood. Nearly 69 percent of respondents reported that OSB was superior to plywood in resistance to delamination. Slightly more than one-third of the survey participants indicated that plywood was more durable than OSB, while 44 percent of respondents indicated that plywood was also superior to OSB in regard to ease of handling. Interestingly, residential homebuilders, by more than a 4-to-1 margin believed that plywood possessed superior shear strength than OSB.

Survey participants were asked to rate the level of importance that they place along eight issues when they purchase lateral loading components for light frame structures. The rating scale that was used in this questioned ranged from 1 = "No Importance" to 5 = "Utmost Importance." With the exception of one issue, that being testing standards and criteria, respondents indicated that all the issues were of importance when they purchased lateral loading components. Wide availability and ease of installation of the product were rated as being the two most important issues that survey participants considered when purchasing lateral loading components.

Table 11. Residential homebuilder perceptions of oriented strandboard and plywood relative superiority in shear wall applications along various product attributes.

	Number of Respondents Indicating . . .			
Product Attribute	Plywood Superior	OSB Superior	Don't Know	*n*
Best edge nailing	39	31	6	76
Best nail holding	40	25	11	76
Consistent quality	23	43	8	74
Delaminating resistant	22	48	5	75
Durability	37	26	12	75
Ease of handling	31	31	12	74
Ease of installation	29	27	15	71
Environmentally friendly	14	22	40	76
Impact resistance	38	19	16	73
Least edge swell	53	12	8	73
Price	5	56	14	75
Shear strength	35	8	28	71
Weather resistance	39	28	9	76
Workability (drilling)	40	26	10	76
Workability (ripping)	41	23	12	76

Table 12. Residential homebuilder importance ratings along various issues when purchasing lateral loading components for light frame structures.

Issue when purchasing lateral loading components	Mean Importance[a]	Standard Deviation	*n*
Product widely available	4.51	0.84	77
Ease of installation	4.22	0.88	77
Up-front component price	4.10	0.90	78
Component installation time	4.09	1.03	78
Ease of product handling	3.99	0.99	77
Product technical support available	3.73	1.12	77
Approval agency	3.70	1.43	76
Testing standards and criteria	3.37	1.24	76

[a] Rating scale was as follows: 1 = "No Importance" and 5 = "Utmost Importance"

Survey participants were also asked to estimate the percentage of their total 2004 lateral loading component purchases that came from a variety of sources. Slightly more than 53 percent of all lateral loading purchases in 2004 were transacted with retailers, followed by wholesalers (40 percent), other (2.7 percent), brokers (1.3 percent), and direct from manufacturer (about 1 percent).

Survey participants were asked several questions in order to explore their knowledge and receptiveness toward WPC lateral loading solutions. First, the homebuilders were asked to indicate those material attributes that they believed were "the most important for a structural wood composite, such as a wood plastic composite." Participants were provided a list of fourteen attributes and were asked to rate them using a scale ranging from 1 = "No Importance" to 5 = "Utmost Importance." Table 13 displays the mean value for each of the fourteen material attributes assessed in the study.

All material attributes assessed with regard their importance for a structural WPC were viewed as being either neutral in importance or important. Four attributes that residential homebuilders rated quite high in importance for structural WPCs were consistent quality, ease of installation, product widely available, and weather resistance.

Table 13. Residential homebuilder ratings of material attribute importance as it related to structural WPCs for sill plate applications.

Material Attribute	Mean Importance[a]	Standard Deviation	*n*
Approval agency	4.00	1.24	72
Bending strength	3.66	1.10	70
Consistent quality	4.42	0.66	73
Ease of installation	4.32	0.75	72
Ease of product handling	3.99	0.87	73
Environmentally friendly	3.88	1.13	74
Product technical support available	3.74	1.10	72
Product widely available	4.44	0.78	73
Testing standards and criteria	3.45	1.22	74
Up-front price	4.04	1.00	72
Weather resistance	4.47	0.63	72
Weight	3.74	1.03	73
Workability (cross-cutting)	4.13	0.75	72
Workability (drilling)	4.15	0.72	73

[a] Rating scale was as follows: 1 = "No Importance" and 5 = "Utmost Importance"

When asked in an open-ended question as to whether they had any concerns regard the use of WPC materials in place of wood materials in residential construction applications, survey participants provided a varied list of concerns; specific responses can be viewed in Table 14. Responses are what one would expect with a new innovative product attempting to substitute for or replace a material used for decades in residential construction applications. Most concerns with WPC as a substitute for wood centered on durability, fasteners, health and environmental issues of product, price/cost, strength, and the WPC interactions with other materials.

Table14. Residential homebuilder concerns with regard to the use of WPC materials in place of wood materials in residential construction applications.

Open-Ended Responses Regarding the Substitution of WPC Material for Wood Materials in Residential Construction Applications[a]	
It would have to be the same width as conventional lumber	Only that they meet the load requirements
Dimensions should match existing hardware sizes “nominal sizes” example 2x6 = 1 ½” x 5 ½”	Building agency support very helpful
Weight	Testing criteria
Long term breakdown	Nail-holding ability – Pre-drill required?
Long term durability	It’s ability to hold a nail
Life span of the product and how to test for that number	Connections
Loss of weight and mass	Nailing-hold strength of nail shank
Longevity	Compatible with conventional attachment methods
Durability	Nail or screw holding ability
Long term use	Fasteners
Long term durability	Edge strength at anchor bolts
Color, fade properties	Strength [mentioned twice]
Plastic composites health issues	Strength of material
Toxins	Delaminating, shear force
Toxicity	Fire, heat, cold
Toxic gasses [emitted] from fire	Inner action qualities between wood materials and wood-plastic composites
Long term health	Compatibility with adjacent building materials
Fire and termite infestation (termites will make their home in a material even if they don’t eat it	Availability
Environmental impact. Plastic does not grow on trees, is not sustainable	Availability is the concern
Environmental-waste disposal	Consistent quality
Environmental	Acceptance by high-end clients
Environmental issues	Price [mentioned four times]
Potential liability of unproven product	Price comparisons
Lack of field testing	Cost will probably be high
History [lack of]	The cost would have to be the same as wood
Remodel-applications could be tough	If it’s more money than treated I probably wouldn’t buy it.
Workability [mentioned four times]	Cost

[a] Comments that share a similar theme have been grouped together by shading.

Next, residential homebuilders were asked to indicate their level of agreement with four questions regarding the industry’s labor force and their own employees as they applied to the use and installation of hold-downs, shear walls, and anchor bolts in light frame structures (Table 15).

Respondents were able to answer each question using a five-point Likert scale that ranged from 1 = “Strongly Disagree,” 3 = “Neutral,” and 5 = “Strongly Agree.”

Survey participants overwhelming agreed that their employees installed hold-downs as specified by the manufacturer, responding with a mean agreement score of 4.23, which was found to be statistically greater than a neutral response of 3. Residential homebuilders were also in general agreement that their employees installed proprietary, prefabricated shear walls exactly as specified by the manufacturer, responding with a mean agreement score of 4.09, which was also found to be statistically greater than a neutral response of 3. Responses to the question asking whether the current labor force is adequately trained to properly install anchor bolts as specified by conventional construction provisions were mixed. The mean level of agreement to the statement was 3.46, which was not found to be statistically different than a neutral response of 3. Finally, survey participants neither agreed or disagreed with the statement that the current labor force is adequately trained to properly install hold-downs as specified by the conventional construction provisions.

Table 15. Residential homebuilder agreement with statements concerning workforce use and installation of hold-downs, shear walls, and anchor bolts.

Statement	Mean Agreement[a]	Standard Deviation	*n*
My employees install hold-downs exactly as specified by the manufacturer	4.23	0.81	75
My employees install proprietary, prefabricated shear walls exactly as specified by the manufacturer	4.06	0.90	72
The current labor force is adequately trained to properly install anchor bolts as specified by the conventional construction provisions	3.46*	0.98	78
The current labor force is adequately trained to properly install hold-downs, as specified by the conventional construction provisions	2.95*	1.14	78

[a] Rating scale was as follows: 1 = “Strongly Disagree,” 3 = “Neutral,” and 5 = “Strongly Agree”
* Mean value was not statistically different than the neutral value of 3.

A set of four additional and more direct questions were asked of survey participants to gauge the degree that certain issues and/or problems may exist within the industry with regard to lateral loading solutions. The results to these four questions are reported in Table 16. Survey participants indicated that on nearly 14 percent of their jobs that they encountered improperly installed hold-downs, while 27 percent of the time they encountered problems between anchor bolt layout and hold-down installation. Residential homebuilders indicated that on nearly three-fourths of their light frame structure jobs that they properly installed all lateral loading components. Interestingly, survey participants reported that on more than 55 percent of new

residential homes constructed in 2004 that they believed the structure had at least one improperly installed hold-down.

Table 16. Residential homebuilder response to questions concerning lateral loading solutions in light frame construction applications.

Statement	Percent	Standard Deviation of Percent	*n*
How often do you encounter improperly installed hold-downs on jobs that you are involved with?	13.9	22.5	77
How often do you encounter problems that exist between anchor bolt layout and hold-down installation on jobs that you are involved with?	27.1	26.8	77
How often do you believe builders properly install all lateral loading components in any particular light framed wood structure job?	71.8	22.2	71
What percentage, do you believe, of new residential homes constructed in 2004 had at least one improperly installed hold-downs?	55.2	35.4	71

Residential homebuilders were asked to indicate whether they had used any of eleven information sources to learn about lateral loading solutions in the past year. As reported in Table 17, more than one-fourth of the respondents indicated that they had used trade publications or a manufacturer's promotional materials to learn about lateral loading solutions within the past year. Approximately one-fifth of the respondents indicated that they had accessed a company website to learn about lateral loading solutions within the past year. About 17 percent of homebuilders indicated that they had used either manufacturer agents/representatives, retailer agents/representatives, or a colleague/associate/partner to learn about lateral loading solutions within the past year. Only one respondent to the survey indicated that they had attended an academic conference to learn about lateral loading solutions in the past year.

After identifying their use of sources of information regarding lateral loading solutions, survey participants were then requested to rate how useful each sources was to them with regarding to learning about lateral loading solutions (Table 18). Respondents were able to answer a five-point Likert-like scale that ranged from 1 = "Not At All Useful" to 5 = "Very Useful." It was assumed that a response of 3 represented a "Neutral" reply. Results indicate that only one source of information concerning lateral loading solutions, namely manufacturer's promotional materials, was found to be significantly greater than a neutral response. In other words, respondents found manufacturer's promotional materials to be useful. Academic conferences and non-company websites were not found to be useful. Survey participants responded in the neutral with regard to the remaining eight other sources of information.

Table 17. Sources of information used by residential homebuilders to learn about lateral loading solutions.

Information Source	Percent of Residential Homebuilder Indicating Use of Source in Past Year
Trade Publication	28.3
Manufacturer’s Promotional Material	25.5
Company Website	21.4
Manufacturer Agent or Representative	17.2
Retailer Agent or Representative	17.2
Colleague/Associate/Partner	17.2
Wholesalers Representative	11.7
Trade Show/Seminar	13.8
Other	4.80
Press Release	4.10
Non-company Website	2.80
Academic Conference	0.70

Table 18. Residential homebuilders’ indication of usefulness for a variety of sources of information to learn about lateral loading solutions.

Information Source	Mean Usefulness[a]	Standard Deviation	*n*
Manufacturer’s Promotional Material	3.55	2.01	55
Retailer Agent or Representative	3.19*	1.22	52
Company Website	3.18*	1.41	55
Manufacturer Agent or Representative	3.16*	1.26	51
Trade Publications	3.07*	1.49	54
Colleague/Associate/Partner	3.04*	1.37	50
Wholesalers Representative	3.02*	1.39	47
Other	2.81*	1.36	16
Trade Show/Seminar	2.63*	1.48	46
Press Release	2.18*	1.54	44
Academic Conference	2.10	1.49	41
Non-company Website	1.93	1.37	43

[a] Rating scale was as follows: 1 = “Not At All Useful” to 5 = “Very Useful”
* Mean value was not statistically different than the neutral value of 3.

Finally, study participants were asked to indicate the trade publications and magazines that they subscribed to that relate to their occupation and/or industry. This question was asked in order to learn where possible WPC material information could potentially be reported and/or promoted so as to increase the knowledge of such products. More than one-fourth off all residential homebuilders in the study indicated that they subscribed to *Fine Homebuilding*. Publications that exhibited subscription rates among the survey participants of 10 percent or greater included *Journal of Light Construction*, *Builder*, *Professional Builder*, and *Remodeling*. A full list of publications mentioned by study participants is provided in Table 19.

Table 19. Trade publication and magazine subscriptions held by residential homebuilders related to their occupation and/or industry.

Trade Publication/Magazine	Numbers of Subscriptions	Percent of Respondents Subscribing (n = 81)
Fine Homebuilding	23	28.4
Journal of Light Construction	15	18.5
Builder	10	12.3
Professional Builder	9	11.1
Remodeling	8	9.9
Custom Home	3	3.7
Homebuilder	3	3.7
Qualified Remodeler	3	3.7
Tools of Trades	2	2.5
Deck Builder	2	2.5
Dwell	2	2.5
Professional Remodeler	2	2.5
Builder News	2	2.5
Rural Builder	2	2.5
Fine Woodworking	2	2.5
American Bungalow	1	1.2
Architectural Digest	1	1.2
Architectural Record	1	1.2
Architecture	1	1.2
Bay Area Home Builder	1	1.2
Big Builder	1	1.2
Builder/Architect	1	1.2
Builder’s Digest	1	1.2
Building Design and Coast	1	1.2
Constructor Business Owner	1	1.2
Engineering News Record (ENR)	1	1.2
Fabric Architecture	1	1.2
Florida Architecture	1	1.2
For All Trades	1	1.2
Home Builder Executive	1	1.2
Metal Construction News	1	1.2
Metal Home Design	1	1.2
Pool and Spa Magazine	1	1.2
Pro Builder	1	1.2
Residential Architecture	1	1.2
Residential Design Building	1	1.2
This Old House	1	1.2
Unique Homes	1	1.2
Western Building News	1	1.2

Conclusions

These results indicate that there are several concerns among engineers and designers with regard to sill plate use in light frame structures. First, engineers and designers identified the sill area as a “weak link” in the connectivity of light frame structures. Second, the overwhelming majority of engineers and designers have either directly experienced problems or witnessed problems with the current labor force with respect to installing anchor bolts and hold-downs as specified by the manufacturer and the respective building code.

When queried about current commercialized products in the lateral loading solutions market, engineers and designers expressed that prefabricated shear walls were an adequate solution for transferring lateral forces. A significant percentage of engineers and designers surveyed preferred *Simpson* brand prefabricated shear walls, as well as *Simpson* brand anchor bolts and hold-downs. The introduction of any new integrated WPC sill plate system will therefore be likely to meet with formidable response from Simpson Strong-Tie Company. Partnering with Simpson Strong-Tie Company in the commercialization of an integrated WPC sill plate system may be an appropriate product development route to follow in order to make certain that the WPC product successfully enters the marketplace and becomes a product of choice specified by engineers and designers and utilized by residential homebuilders.

Engineers and designers were found to be fairly unfamiliar with WPCs, as well as engineered WPCs. However, engineers and designers indicated that they were receptive to exploring the use of a WPC sill plate. Finally, engineers and designers of light frame structures found manufacturers’ promotional materials and manufacturers’ websites useful for learning about lateral loading components.

Residential homebuilders of the seismic regions of the United States were found to be relatively small-scale in structure, mimicking the homebuilders market nationally in this regard. For instance, the average residential homebuilder employed nine individuals full-time and reported revenues of approximately $2 million in 2004.

Interestingly, residential homebuilders were not as familiar as one might have assumed with regard to contemporary sill plate issues. For example, the average respondent indicated that s/he was only somewhat familiar with the voluntary industry ban of CCA for use in sill plate applications. Homebuilders were also only somewhat familiar with the use of non-corrosive hardware for sill place applications.

Residential homebuilders were familiar with WPCs, but only somewhat familiar with engineered WPCs. Homebuilder familiarity with WPCs may be due to the fact that the market share of such material in residential deck applications has risen to such a level that it is nearly impossible to not be familiar with the material.

Generally, residential homebuilders expressed that they believed that the homes that they constructed (in seismic areas) were over-engineered (“way over-engineered,” “overkill” “houses too rigid,” engineers tend to over engineer”). This somewhat pervasive perception among homebuilders could be very problematic in attempting to develop and market an engineered

WPC sill plate into the market. The *engineered* nature of the WPC product itself may be viewed as additional engineering of an already over-engineered light frame structure. Many builders may see proper training in the installation of hold-downs and anchor bolts as the solution to the improved wall-to-foundation counnections.

Similar to results of the engineers and designers survey, residential homebuilders were also found to have particularly high brand preference for Simpson Strong-Tie Company products used in wall-to-foundation connections. Combined with the engineers and designers findings, this suggests that the development of an engineered WPC sill plate product may find formidable competitive “push-back” from Simpson.

When purchasing lateral loading solutions, residential homebuilders expressed that wide product availability, ease of installation, and up-front component cost were important attributes considered in their purchasing decision. These results suggest that if an engineered WPC is developed for the market, then it should probably be highly standardized so as to facilitate ease of use and common production parameterization. For instance, interchangeability between one manufacturer’s engineered WPC sill plate with another manufacturer’s sill plate will enhance the perceived availability of the product by homebuilders.

When residential homebuilders were specifically asked to indicate the attributes that perceived as being most important with regard to an engineered WPC sill plate, they indicated that agency approval, bending strength, consistent quality, ease of installation, and ease of product handling as being the five most important attributes. These stated attributes reinforce the idea that builders would prefer and engineered WPC product that closely mimics the current products they use for wall-to-foundation connections.

Despite residential homebuilders indicating that their own employees typically installed hold-downs correctly, they tended to disagree that the workforce installing hold-downs is adequately trained. These results somewhat confirm those shared by engineers and designs indicating that pervasiveness of improperly installed hold-downs and anchor bolts in light frame construction. As such, the engineered WPC sill plate application has an opportunity to solve a market issue with regard to proper installation of a critical connection in light frame structures, especially in those markets where the structure could experience high lateral loading situations.

Results of the residential homebuilder survey suggest that promotion of engineered WPC sill plate applications should be targeted at trade publications and manufacturer’s promotional materials. Manufacturer’s promotional materials, in particular, were found to be especially useful by survey participants. Non-company websites, trade shows, and academic conferences were not used as information sources with regard to lateral loading solutions among the homebuilders surveyed. In additional homebuilders found little usefulness in these three promotion vehicles.

In sum, the results of both surveys suggest substantial opportunities to address problems that exist in the light frame construction market as it pertains to wall-to-foundation connections. However, the solution to the problem (i.e., engineered WPC) has to be similar in its function, form (to some degree), price, and availability as current products in the marketplace (i.e., treated solid wood).

One limitation of this study concerns the fact that no questions were asked of survey participants to drill down into their perceptions of whether the wall-to-foundation connection was truly perceived to be such an issue of significance that new innovative products should be developed and marketed to reduce the incidence of poor and inadequate installation of anchor bolt and hold-downs. While residential home builders and engineers and designers readily express that anchor bolts and hold-downs are often improperly installed, results did not indicate a pressing need for a solution.

Another limitation of this study is that neither survey population was provided with a prototype product. Explanation of the product was often difficult with engineers and designers given the radical form of the product relative to current solid wood/metal fastener connections. Had a visual or actual prototype of the product been available to survey respondents, the results of the study may have been different than herein reported.

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Figures

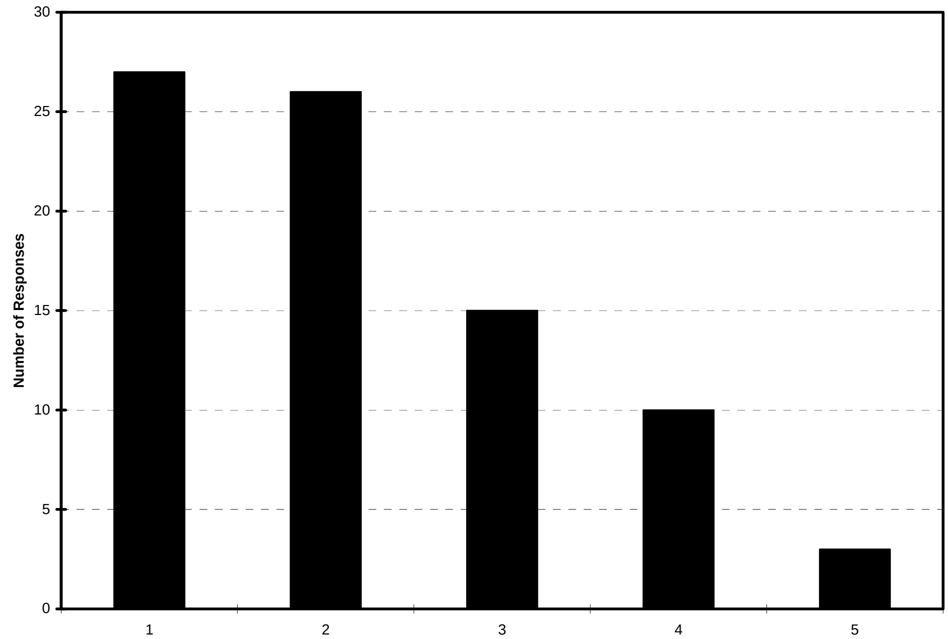


Figure 1. Residential homebuilder familiarity with the voluntary ban of CCA treated wood in residential home construction applications.
Note: Rating scale was as follows: 1 = "not familiar," 2 = "somewhat familiar," 3 = "familiar," 4 = "very familiar," and 5 = "extremely familiar"

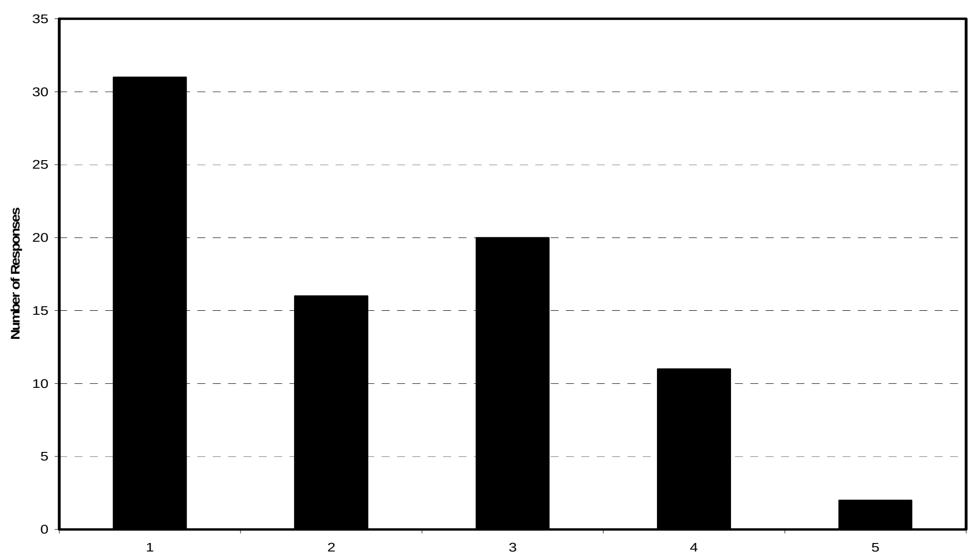


Figure 2. Residential homebuilder familiarity with the use of non-corrosive hardware with second generation wood treatments, such as ACA, ACQ, Cu-HDO, etc.
Note: Rating scale was as follows: 1 = "not familiar," 2 = "somewhat familiar," 3 = "familiar," 4 = "very familiar," and 5 = "extremely familiar"

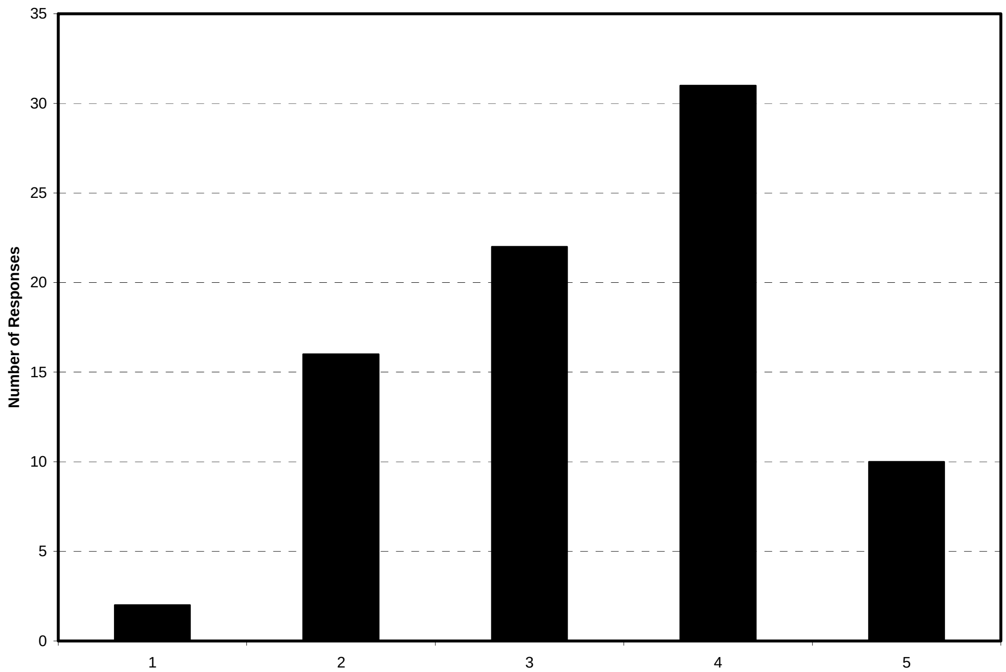


Figure 3. Residential homebuilder familiarity with WPCs.
Note: Rating scale was as follows: 1 = “not familiar,” 2 = “somewhat familiar,” 3 = “familiar,” 4 = “very familiar,” and 5 = “extremely familiar”

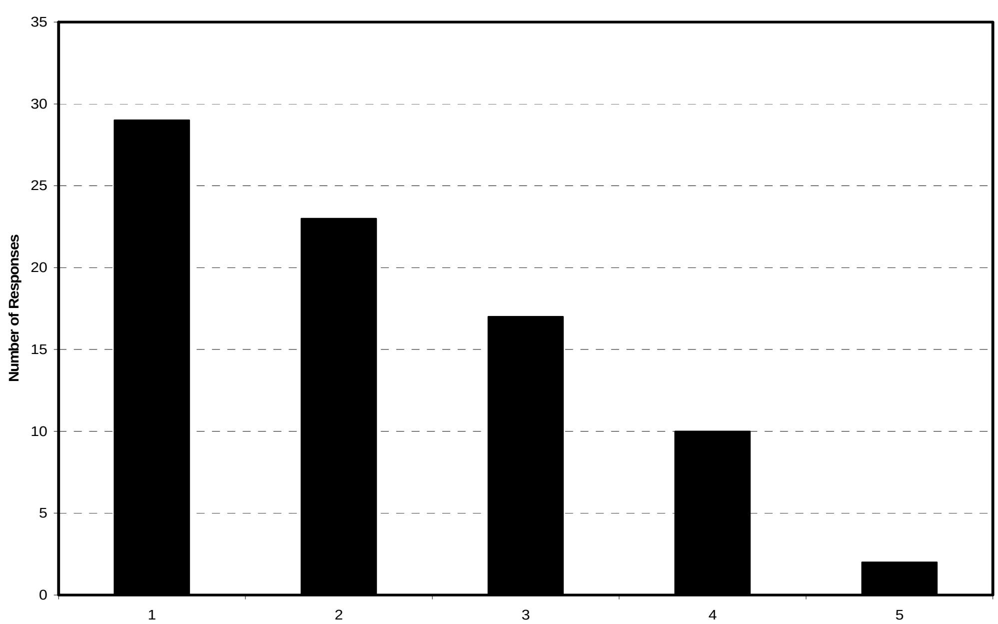


Figure 4. Residential homebuilder familiarity with engineered WPCs.
Note: Rating scale was as follows: 1 = “not familiar,” 2 = “somewhat familiar,” 3 = “familiar,” 4 = “very familiar,” and 5 = “extremely familiar”

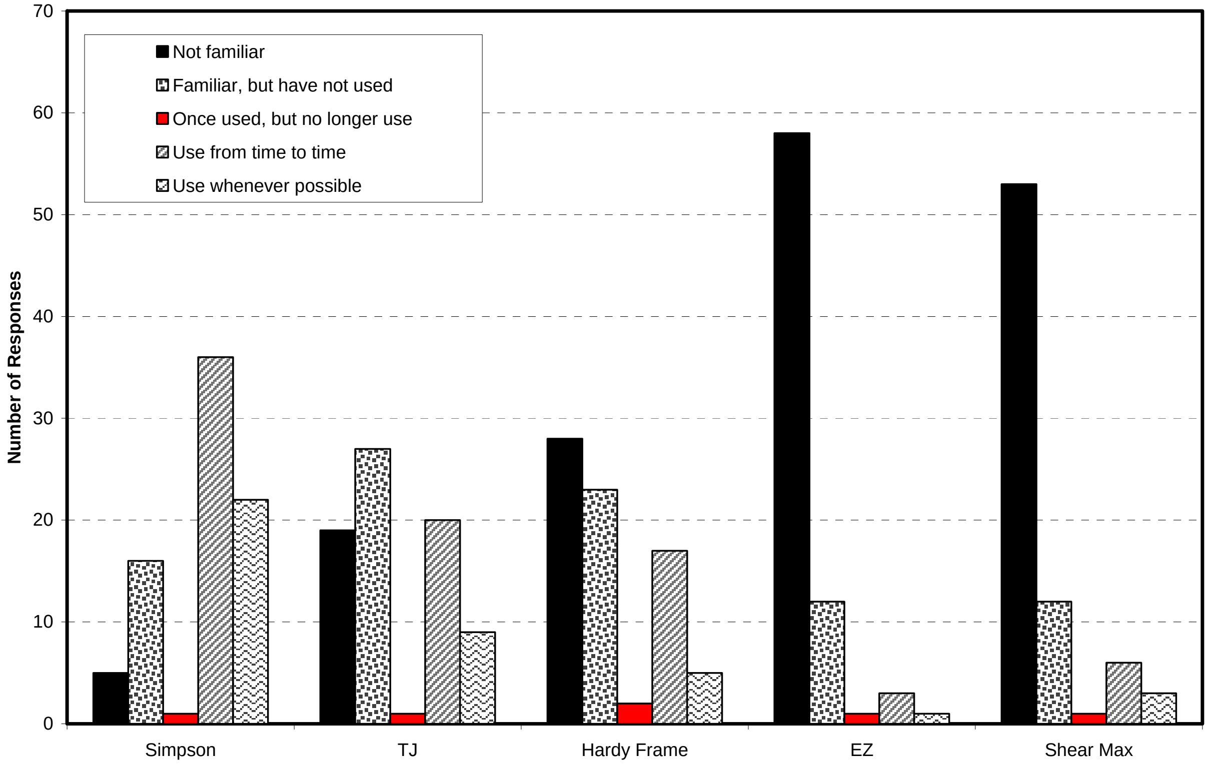


Figure 5. Distribution of residential homebuilder responses with regard to their familiarity and use of five commercial shear wall products currently available in the marketplace.

Appendix

Engineers and Designers Telephone Survey Script

Given that you are an engineer/designer of light frame structures, I am interested in your views on various technical issues within the light frames structures engineering/design field. This interview is looking specifically at issues concerning lateral loading. This survey is funded by the U.S. Navy.

1. What is your employment position?

    ____

2. How many years have you been designing/engineering light frame structures?

    _________years

3. What state or states are you licensed to engineer/design light frame structures in?

    ____

    ____

4. Is there a seismic design category you primarily design/engineer for?

    A B C D1 D2 E

5. Do you design for a special wind region?

    ☐ Yes ☐ No

If yes, which region?

____

Next, I'd like to discuss establishing a lateral load path and connectivity in a light framed structure.

6. When meeting code requirements (conventional construction) for lateral forces in light framed structures, which one of the listed connections do you believe is <u>most</u> likely to fail?

☐ Roof diaphragm to shear wall connection	(roof blows off)
☐ Shear wall to rim joist/sill plate connection	(structure uplifts)
☐ Sill plate to foundation connection	(structure slides off foundation)
☐ Internal shear wall strength	(wall failure)
☐ Sill plate bearing capacity	(sill plate splits or crushes)
☐ All could fail equally	

7. When meeting code requirements (conventional construction) for lateral forces in light framed structures, which one of the listed connections do you believe is <u>least</u> likely to fail?

☐ Roof diaphragm to shear wall connection	(roof blows off)
☐Shear wall to rim joist/sill plate connection	(structure uplifts)
☐ Sill plate to foundation connection	(structure slides off foundation)
☐ Internal shear wall strength	(wall failure)
☐ Sill plate bearing capacity	(sill plate splits or crushes)
☐ All could fail equally	

8. Do you think there are issues or problems with the current lateral forces code system?

☐ Yes ☐ Neutral ☐ No

If yes, what are the issues/problems?

___

___

___

9. Which do you prefer – a 3x or thicker sill, a 2x sill with twice as many sill anchors, or another type of sill system?

☐ 3x or thicker sill

☐ 2x sill with twice as many sill anchors

☐ another type of sill system___________________________

10. Given current conventional design criteria, do you believe metal connectors put too much compression stress on sill plates and rim joists?

☐ Yes ☐ No

Next, I'd like to discuss shearwall holdowns

11. Do you believe the current code requirement for hold downs is adequate?

☐ Yes ☐ No

If no, why not?

____

____

12. Would you be receptive to an alternative light frame building system that did not require traditional holdowns, but exhibited equivalent or superior capabilities relative to traditional holdowns?

☐ Yes ☐ No

If no, why not?

____

____

13. Do you believe the current labor force is adequately trained to properly install anchor bolts, as specified by the conventional design code?

☐ Yes ☐ No

14. Do you believe the current labor force is adequately trained to properly install holdowns, as specified by the conventional design code?

☐ Yes ☐ No

15. How often do you encounter improperly installed holdowns on jobs that you're involved with?

______________% of jobs

16. How often do you encounter problems that exist between anchor bolt layout and holdown installation on jobs that you're involved with?

______________% of jobs

17. Do you have an anchor bolt and holdown brand preference?

Simpson USP Tamyln Other____________________

18. Why do you prefer this brand?

____

Next, I'd like to discuss prefabricated shear walls

19. Have you designed or engineered a structure using prefabricated shear walls?

☐ Yes ☐ No

20. Do you think prefabricated shear wall sections are an adequate solution for transferring lateral forces?

☐ Yes ☐ No

If no, why not?

____

____

21. I am going to go over a list of factors as they pertain to the use of prefabricated shear walls. Please indicate on a scale ranging from 1 (not important at all) to 5 (very important) how these factors would affect your adoption of prefabricated shear walls.

Ability to resist high lateral loads in short sections of wall.

1 2 3 4 5

Wall manufactured in a factory setting.

1 2 3 4 5

Perfectly constructed wall.

1 2 3 4 5

Potentially fewer installation errors.

1 2 3 4 5

The cross over between design categories of braced steel frames and wood shear walls.

1 2 3 4 5

The high use of holdowns in prefabricated wall segments.

1 2 3 4 5

Essentially, that prefabricated shear wall units only address the issue of internal wall strength and not many other forces, such tie-down forces, bearing capacity, etc.

1 2 3 4 5

22. Are there any other technical factors that influenced your adoption of prefabricated shear walls?

____

____

23. Which brands of prefabricated shear walls have you specified?

Simpson Trus-Joist Shear Max Hardy Frame Other_____________

24. Which brands of prefabricated shear walls do you prefer?

Simpson Trus-Joist Shear Max Hardy Frame Other_____________

25. Why was that respective brand chosen?

____

____

____

26. Do you have any comments or concerns about the performance of prefabricated shear walls?

____

____

____

Next, I'd like to discuss panel products

27. Even though the code views plywood and OSB as interchangeable, do you prefer one over the other for shear walls?

☐ OSB over plywood

☐ Plywood over OSB

☐ No preference

Explain your choice?

____

____

____

28. In many areas, 3x's at panel joints are now required. Do you agree with this requirement?

☐ Yes ☐ No ☐ Not a requirement

Why not?

____

____

____

Next, I'd like to discuss a few installation issues

29. How often do you believe builders properly install all lateral loading components in any particular light framed wood structure job?

______________% of jobs

30. Would you be interested in an integrated sill plate that would already have slots for stud placement?

☐ Yes ☐ No

If no, why not?____

____

31. Would you be interested in building systems that utilized integrated modular prefabricated components?

☐ Yes ☐ No

If no, why not? ____

____

32. I would like you to rate the importance of these two issues when specifying building components in light frame structures. Using a scale of 1 (not at all important) to 5 (very important)

Component installation time

1 2 3 4 5

Up-front component price

1 2 3 4 5

Next, I'd like to discuss wood plastic composites

How familiar are you with the following issues:

33. Voluntary industry ban of CCA for use in residential homes.

☐ Not familiar

☐ Somewhat familiar

☐ Familiar

☐ Very familiar

☐ Extremely familiar

34. The use of non-corrosive hardware when using second generation chemically treated wood, such ACA, ACQ, Cu-HDO.

☐ Not familiar

☐ Somewhat familiar

☐ Familiar

☐ Very familiar

☐ Extremely familiar

35. How familiar are you with wood-plastic composites?

- ☐ Not familiar
- ☐ Somewhat familiar
- ☐ Familiar
- ☐ Very familiar
- ☐ Extremely familiar

36. If a wood-plastic composite sill plate could be developed with comparable design values as treated wood sill plates, would you specify the wood plastic composite sill plate?

Definitely Probably Neutral Probably Not Definitely Not

37. Please rate how receptive you would be to exploring the use of wood plastic composite materials for the following components.

Component	Not Receptive			Neutral	Very Receptive	
Sill Plate		1	2	3	4	5
Rim Joist		1	2	3	4	5
Window Sill		1	2	3	4	5
Window/Door Header	1	2	3	4	5	

38. Do you have any concerns regarding the use of wood-plastic composite materials in place of structural wood materials? Such as sill plates or rim joists. Please specify.

a. ____

____

b. ____

____

c. ____

____

Next, I'd like to discuss how you obtain information about lateral loading solutions

39. In the past year, have you used any of the following means to obtain information about lateral loading solutions?

Manufacturer promotional materials	Yes	No
Manufacturer Agent or Rep.	Yes	No
Wholesalers Rep.	Yes	No
Retailer Agent or Rep.	Yes	No
Trade publication/magazine	Yes	No
Press release	Yes	No
Colleague/ associate/ partner/ collaborator	Yes	No
Internet web site (company)	Yes	No
Internet web site (non-company)	Yes	No
Trade show/ seminar	Yes	No
Academic conference	Yes	No
Other__________________________		

40. I'd like you to rate what types of information you find most useful? (1 = very useful, 2 = somewhat useful, 3 = neutral, 4 = not very useful, 5 = not at all useful)

Manufacturer's promotional materials	1	2	3	4	5
Manufacturer's Agent or Rep.	1	2	3	4	5
Wholesaler's Rep.	1	2	3	4	5
Retailer's Agent or Rep.	1	2	3	4	5
Trade publication/magazine	1	2	3	4	5
Press release	1	2	3	4	5
Colleague/ associate/ partner	1	2	3	4	5
Internet web site (company)	1	2	3	4	5
Internet web site (non-company)	1	2	3	4	5
Trade show/ seminar	1	2	3	4	5
Academic conference	1	2	3	4	5
Other___________________	1	2	3	4	5

41. Do you find that samples are useful for learning about new products?

☐ Yes ☐ No

42. Do you find that demonstrations are useful for learning about new products?

☐ Yes ☐ No

43. Do you receive or subscribe to any trade publications or magazines?

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________

44. Have you attended any trade shows, seminars, or academic conferences in the last two years?

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________

Lastly, I am going to ask a few demographic questions about you and your firm that can assist us in better understanding the answers you have provided in previous sections of this interview.

45. What is your title?

____

46. How many employees are employed at your firm?

____

47. How many light frame structures did you/firm design/engineer in 2004?

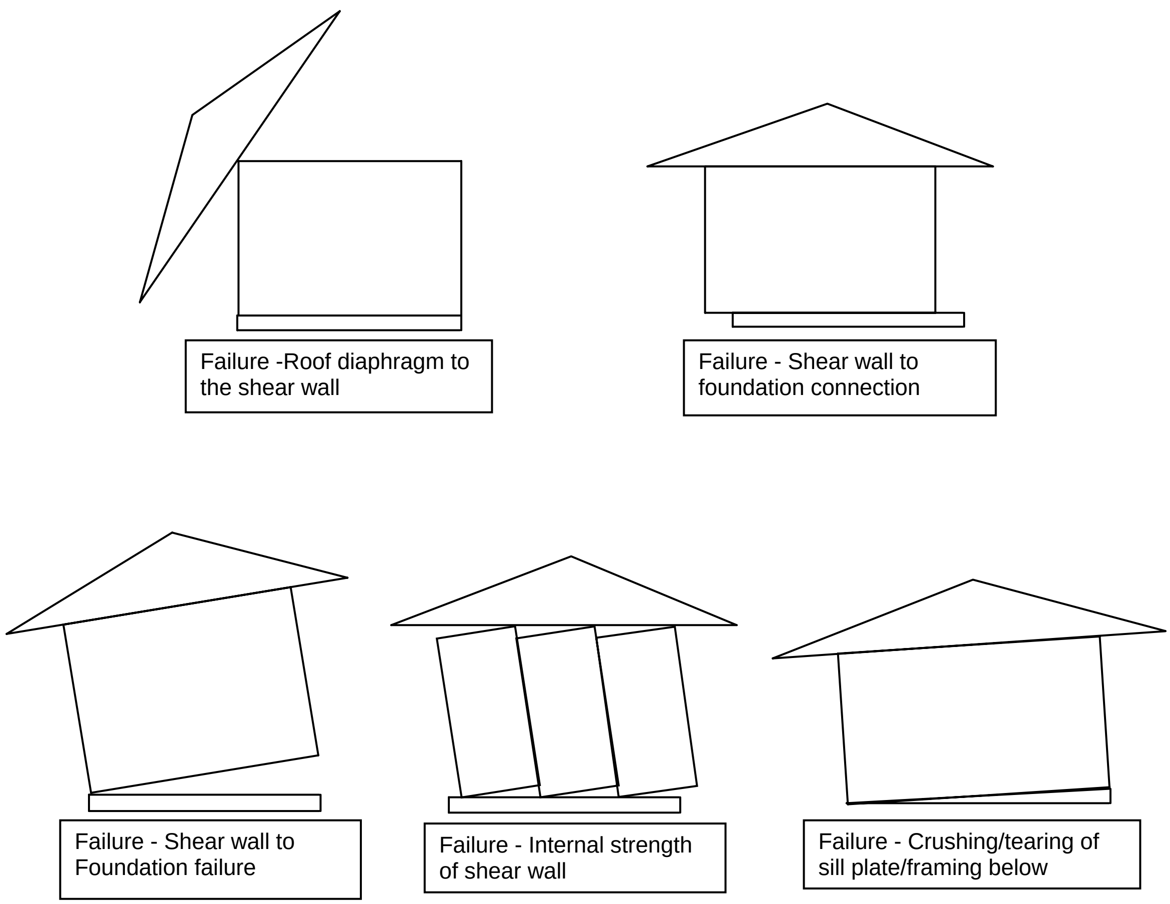
____

48. Do you plan to design/engineer more or less in 2005?

☐ More ☐ Less

Residential Homebuilder Mail Survey Instrument

Light Frame Building Durability in the 21st Century: A Survey of Homebuilders



EXAMPLES OF LATERAL LOADING FAILURES

September 15, 2005

You have been selected to participate in a study that will help make wood light-frame structures more durable. This study is funded by the Office of Naval Research. The Navy's goal is to increase the durability of their wood light frame structures, as well as disseminate the information to the private sector. The results of this survey will be available to you if you would like to receive a copy of the results. All of your responses to survey questions and your identity will be strictly confidential and you will not be identified in any way in any reports or presentations. The questions that follow relate to lateral loading conditions on light-frame wood structures. Also included are questions concerning current products, products that could be developed, and general industry issues.

Additionally, the information you provide will assist me in my studies and allow me to complete the requirements for my degree. I sincerely appreciate the time and answers you give to this study.

Dan Mottern
Graduate Student
University of Idaho
Moscow, Idaho

This survey should be completed by a person in your company who oversees the building of light-frame wood structures, such as single family dwellings, duplexes, and other wood framed structures that are less than three stories. The person should be instrumental in the actual construction and the acquisition of building materials for construction of light-frame wood structures.

What is your title? ____

Would you like to receive a summary of the results from this study?

- ❑ **Yes**
- ❑ **No**

If you choose to receive a copy of the results, what is your address or e-mail you would like to receive your copy at?

____

____

____

____

Please Note:

Lateral loading building components include the following:

- **Anchor bolts**
- **Dragline struts**
- **Foundation anchors**
- **Hold-downs**
- **Hurricane straps and ties**
- **Mudsill anchors**
- **Pre-deflected hold-downs**
- **Prefabricated shear walls**
- **Seismic straps and ties**
- **Tension ties**
- **Wood shrinkage compensation devices**

Proprietary, prefabricated shear walls include, but are not limited to, the following:

- **E Z Tech's *Z-Wall***
- **Shear Transfer System's *Shear Max* panel**
- **Simplified Structural System's *Hardy Frame***
- **Simpson's *Strong-Wall Shearwall***
- **Trus-Joist's *TJ-Shear* Panel**

How familiar are you with the following issues:

1. The voluntary industry ban of CCA treated wood in residential homes.

- ❑ Not familiar
- ❑ Somewhat familiar
- ❑ Familiar
- ❑ Very familiar
- ❑ Extremely familiar

2. The use of non-corrosive hardware with second generation wood treatments, such ACA, ACQ, Cu-HDO, etc.

- ❑ Not familiar
- ❑ Somewhat familiar
- ❑ Familiar
- ❑ Very familiar
- ❑ Extremely familiar

3. How familiar are you with wood-plastic composite products? (Non-structural – e.g. *Trex* decking, *Rhino* decking)

- ❑ Not familiar
- ❑ Somewhat familiar
- ❑ Familiar
- ❑ Very familiar
- ❑ Extremely familiar

4. How familiar are you with *engineered* wood-plastic composite materials?

- ❑ Not familiar
- ❑ Somewhat familiar
- ❑ Familiar
- ❑ Very familiar
- ❑ Extremely familiar

5. Do you believe there are issues or problems with the current code system concerning lateral forces within the conventional construction provisions for light-frame construction?

❑ Yes ❑ Neutral ❑ No

5b. If yes, what are the issues/problems?

____

____

____

6. **Would you be receptive to an alternative light-frame building system that did not require traditional hold-downs, but exhibited equivalent or superior capabilities relative to traditional hold-downs?**

❑ Yes ❑ No

6b. **If no, then why not?**

____

____

____

7. **Do you have a hold-down brand preference?**

❑ Simpson ❑ USP ❑ Tamyln ❑ Other_____________________

7b. **Why do you prefer this brand of hold-down?**

____

____

____

8. **Below are five phrases that indicate your company's relationship with products listed below. Please read the phrases and choose a number for each product.**

1 – My company is not at all familiar with this product
2 – My company is familiar with this product, but has never used it
3 – My company has used this product, but no longer does
4 – My company uses this product from time to time for certain applications
5 – My company prefers this product and uses it whenever possible

Please indicate by number (1,2,3,4,5) the phrase above that best fits your company's relationship with each product below.

_______Simpson's *Strong-Wall Shearwall*
_______Trus-Joist's *TJ-Shear* Panel
_______Simplified Structural System's *Hardy Frame*
_______E Z Tech's *Z-Wall*
_______Shear Transfer System's *Shear Max* panel

9. **Would you be interested in an integrated sill plate system that would incorporate slots for stud placement?**

❑ Yes ❑ No ❑ Don't Know

10. **Even though the conventional construction provisions views plywood and OSB as interchangeable, do you prefer one over the other for shear walls?**

❑ OSB over plywood
❑ Plywood over OSB
❑ No preference

11. **For each variable listed below, please indicate whether plywood or OSB is the superior product for shear wall applications. (Assume sheathing panels – CDX plywood and sheathing grade OSB)**

Variable	Plywood	OSB	Don't Know
Best edge nailing	❑	❑	❑
Best nail holding	❑	❑	❑
Consistent quality	❑	❑	❑
Delaminating resistance	❑	❑	❑
Durability	❑	❑	❑
Ease of handling	❑	❑	❑
Ease of installation	❑	❑	❑
Environmentally friendly	❑	❑	❑
Impact resistance	❑	❑	❑
Least edge swell	❑	❑	❑
Price	❑	❑	❑
Shear strength	❑	❑	❑
Weather resistance	❑	❑	❑
Workability (drilling)	❑	❑	❑
Workability (ripping)	❑	❑	❑

12. **Please indicate the importance of the following issues when purchasing lateral loading components for light frame structures.**

Issue	No Importance 1	2	3	4	Utmost Importance 5
Approval agency	1	2	3	4	5
Component installation time	1	2	3	4	5
Ease of installation	1	2	3	4	5
Ease of product handling	1	2	3	4	5
Product technical support available	1	2	3	4	5
Product widely available	1	2	3	4	5
Testing standards and criteria	1	2	3	4	5
Up-front component price	1	2	3	4	5

13. **In 2004, which of the following entities did you purchase lateral loading components? Please indicate what percentage of your total component purchases came from each entity.**

Wholesalers	________%
Retailers	________%
Buying group/Co-op	________%
Agents	________%
Brokers	________%
Direct from the manufacturer	________%
Other (Please specify) ____________________	________%

Total = 100%

14. **In 2004, approximately what percentage of your company's gross sales revenues was generated from constructing the following structures?**

Custom homes (single family)	____________%
Tract homes (single family)	____________%
Multi-family dwellings (e.g., duplex, apartment)	____________%
Wood light-frame commercial	____________%
Wood other than light-frame	____________%
Non-wood light-frame buildings	____________%
Non-wood other than light-frame	____________%
Other (please specify) ______________________	____________%

Total = 100%

15. **What material attributes do you believe are the most important for a structural wood plastic composite, such as a wood plastic composite sill plate?**

Material Attribute	No Importance				Utmost Importance
Approval agency	1	2	3	4	5
Bending strength	1	2	3	4	5
Consistent quality	1	2	3	4	5
Ease of Installation	1	2	3	4	5
Ease of product handling	1	2	3	4	5
Environmentally friendly	1	2	3	4	5
Product technical support available	1	2	3	4	5
Product widely available	1	2	3	4	5
Testing standards and criteria	1	2	3	4	5
Up-front price	1	2	3	4	5
Weather resistance	1	2	3	4	5
Weight	1	2	3	4	5
Workability (cross-cutting)	1	2	3	4	5
Workability (drilling)	1	2	3	4	5

16. **If an engineered wood-plastic composite sill plate could be developed with comparable design values as treated wood sill plates, would you be receptive of the wood plastic composite sill plate? (circle one phrase below)**

Definitely   Probably   Neutral   Probably Not   Definitely Not

17. **Do you have any concerns regarding the use of wood-plastic composite materials in place of wood materials?**

1.____

____

2.____

____

18.	**Please rate your agreement with the following statements**					
Statement	**Strongly Disagree**		**Neutral**		**Strongly Agree**
The current labor force is adequately trained to properly install hold-downs, as specified by the conventional construction provisions.	❑	❑	❑	❑	❑
The current labor force is adequately trained to properly install anchor bolts as specified by the conventional construction provisions.	❑	❑	❑	❑	❑
My employees install hold-downs exactly as specified by the manufacturer.	❑	❑	❑	❑	❑
My employees install proprietary, prefabricated shear walls exactly as specified by the manufacturer.	❑	❑	❑	❑	❑

19. How often do you encounter *improperly* installed hold-downs on jobs that you're involved with?

_______________% of jobs

20. How often do you encounter problems that exist between anchor bolt layout and hold-down installation on jobs that you're involved with?

_______________% of jobs

21. How often do you believe builders properly install all lateral loading components in any particular light framed wood structure job?

_______________% of jobs

22. What percentage, do you believe, of new residential homes constructed in 2004 had at least one improperly installed hold-down?

_______________% of all new residential homes

23. How many employees are employed at your firm?

__________Full-time year-round

__________Part-time year-round

__________Full-time seasonal

__________Part-time seasonal

24. **In the last year, have you used any of the following means to obtain information about lateral loading solutions?**

Manufacturer promotional materials	Yes	No
Manufacturer Agent or Rep.	Yes	No
Wholesalers Rep.	Yes	No
Retailer Agent or Rep.	Yes	No
Trade publication/magazine	Yes	No
Press release	Yes	No
Colleague/associate/partner/collaborator	Yes	No
Company web site (example: Simpson website)	Yes	No
Non-company web site (example: blog)	Yes	No
Trade show/seminar	Yes	No
Academic conference	Yes	No
Other___________________________	Yes	No

25. **For the means you obtained information above (question 23), please indicate how useful those types of information are. Please circle, 1 = Not at all useful, 2 = not very useful, 3 = neutral, 4 = somewhat useful, 5 = very useful**

	Not at all Useful				Very Useful
Manufacturer's promotional materials	1	2	3	4	5
Manufacturer's Agent or Rep.	1	2	3	4	5
Wholesaler's Rep.	1	2	3	4	5
Retailer's Agent or Rep.	1	2	3	4	5
Trade publication/magazine	1	2	3	4	5
Press release	1	2	3	4	5
Colleague/associate/partner/collaborator	1	2	3	4	5
Company web site (example: Simpson website)	1	2	3	4	5
Non-company web site (example: blog)	1	2	3	4	5
Trade show/ seminar	1	2	3	4	5
Academic conference	1	2	3	4	5
Other_____________________________	1	2	3	4	5

26. **Please list any trade publications or magazines that you receive or subscribe to?**

1.____

2.____

3.____

27. **For 2004, what was your company's gross revenue?**

$_____________________________

Durable Wood Composites for Naval Low-Rise Buildings

Effect of Co-polymer Coupling Agent on Properties of a Commercial OSB Phenol Formaldehyde Resin

Integrated Sill Plate Rim Board Elements Progress Report

Task C2 -- Mechanisms to improve the durability of Oriented Strand Board (OSB)

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Abstract

A mechanism to improve toughness of a commercial oriented strand board (OSB) phenol formaldehyde (PF) resin is presented in this study. Effect of adding maleic anhydride polyolefins (MAPO), namely maleic anhydride polypropylene (MAPP) and maleic anhydride polyethylene (MAPE), on the toughness of phenol formaldehyde (PF) resin is investigated. Differential scanning calorimetry (DSC) was used to determine curing parameters. Dynamic properties of resin blends were analyzed using dynamic mechanical analysis (DMA) and toughness of adhesive blends was evaluated using fracture analysis. Particle size analysis using SEM indicated an emulsified form of MAPP resulted in a better distribution resin blend than blends with MAPP particles. DSC results indicated that 2.5 minutes at 145 °C was adequate for nearly 98% curing of the resin blends. With addition of MAPP, a dynamic temperature ramp test conducted with DMA showed an improvement in the storage modulus (E′) or stiffness of the resin system during cure. Cured laminates were again dynamically ramped and damping property (tanδ) was examined at three discreet temperatures (35 °C, 40 °C and 45 °C). Examination of tanδ at these temperatures with blends of MAPP or MAPE showed improvement in damping property. Fracture energies (G_{Ic} and G_{Ia}) at 12% MC were increased with the addition of MAPP at lower proportions (1.5% and 3%), whereas, addition of MAPE showed a reduction in fracture energies. Furthermore, after 24-hour soak, specimens with MAPP showed significant improvements in G_{Ic} and G_{Ia}; however, addition of MAPE resulted in a reduction of fracture energies. On the basis of these results MAPP anionic emulsion was chosen to blend with PF resin for fabrication of oriented strand composites (OSC) test boards.

Introduction

Phenol formaldehyde (PF) is a widely used resin to manufacture exterior grade oriented strand board (OSB), a commonly used sheathing material in low-rise building construction. OSB has the ability to absorb and dissipate moisture if allowed to breath, but often due to poor constructional practices and improper use of vapor barriers could be exposed to high humidity or repeated wet-dry cycles resulting in its rapid degradation. When exposed to high humidity, improving moisture resistance of OSB panels would make them less susceptible to absorbing moisture required for mold and fungal growth. Though panels made of polymeric methylene diphenyldiisocyanate (pMDI) have much better moisture resistance, but the associated high cost and hazardous production procedure make this process less desirable for making durable OSB.

Several methods have been used to reduce the inherent hygroscopicity of wood, including chemical modification (Chow et al. 1996, Clemons et al. 1992, Youngquist et al. 1986, Arora et al. 1981). Though these chemical treatments improved the moisture durability of the product, they significantly reduced their mechanical properties. Thus, there is a motivation to find an alternate method to produce a moisture resistant OSB panel without significantly compromising the mechanical properties, such as stiffness and strength. In this study, it is hypothesized that adding co-polymer coupling agents, such as maleic anhydride polyolefins (MAPO), to PF resin would impart toughness to brittle PF resin. Addition of MAPO to resin could result in a phase separation leading to a reduction in resin brittleness thus improving its toughness. Minimizing brittleness would require greater energy to propagate a crack and result in bond failure between the strands. This would result in a less void generation within the composite. Furthermore,

thermoplastic in MAPO could potentially act as a moisture barrier within the matrix by bulking the voids.

Objectives

The goal of this study is to understand the behavior of PF resin in regards to its dynamic properties and toughness when blended with varying proportions of co-polymer coupling agents, namely MAPP and MAPE. Specific tasks formulated to achieve this objective are to:

1. Evaluate the effect of particle size of MAPO on its distribution in the cured adhesive blend and the dynamic properties of cured adhesive system.
2. Examine the effect of blending MAPP with PF resin on its curing parameters, namely curing temperature and curing time.
3. Investigate the effect of blending MAPP and MAPE with PF resin on dynamic properties of adhesive blends.
4. Evaluate the fracture toughness of the resin blends to study the effects of MAPP and MAPE mixed with PF resin.

These tasks will facilitate in determining whether to use MAPP or MAPE to blend with PF resin for improving its toughness when applied as a binder in manufacturing oriented strand composite panels and understand curing behavior of the blend. The study will also aid in deciding what form the co-polymer coupling agent (powder or emulsion) would be most effective to blend with PF resin.

Literature Review

Toughening of PF

Phenol formaldehyde, commonly used resin for OSB, has some excellent properties, but in glassy state it is brittle in nature (Chen and Lee 1995) thus exhibiting lower toughness. The low toughness of PF is inherent from rigid nature of phenolic structure. The toughness and flexibility can be increased with the addition of modifiers like acrylonitrile butadiene styrene (ABS), methacrylate butadiene styrene (MBS), polyaryl ethers, phenylene oxide and rubber particles(Gardziella et al 1999, Kim and Robertson 1992, Chen and Lee 1995 , Pearson and Yee 1993, Romano et al. 1994 and Mezzenga and Manson 2001). The addition of polyaryl ether into the resin system nearly tripled the fracture toughness. The modification can be either a chemical modification or a physical one. The chemical modification can be achieved by introduction of a flexible polymer segment into the rigid phenolic backbone during the preparation of resol resin (Gardziella et al. 1999).

In physical modification high molecular weight polymers, especially thermoplastics, are added to resin systems providing more flexibility to the polymer blend through phase separation, thus imparting toughness. This method of improving toughness is common in the epoxy systems, where a ductile thermoplastic phase is introduced in the tough epoxy phase (Gardziella et al. 1999). Fracture toughness of epoxy resin was shown to increase with addition of thermoplastic in the adhesive system (Kim and Robertson 1992). Chen et al. (1995) significantly improved fracture toughness energy of an epoxy system with the addition of carboxyl terminated butadiene rubber. Boogh et al. (1999) found that addition of hyperbranched polymers (HBP) in the brittle

thermoset system causes improvement in the toughness of the cured system. Moreover, it increased the tensile strength up to 25% and reduced the internal stress generation during cure of the thermoset. Same class of additive was also used by Mezzenga and Manson (2001) as a thermoset resin toughner and obtained significant improvement in fracture toughness. Pearson and Yee (1993) used poly phenylene oxide to toughen epoxy; it improved fracture toughness linearly with volume fraction of the toughner in the epoxy system.

Romano et al. (1994) effectively used liquid rubber and phenoxy polymer together to toughen epoxy resin system. Their study showed that slow curing of the adhesive blend results in optimum morphology and phase separation, a key to effective toughening. Interfacial bonding and particle size of the modifier in the cured system depend on parameters such as curing rate and compatibility of epoxy and the modifier; these factors affect the fracture toughness. Manzione and Gillham (1981) studied thermo-mechanical properties and extent of phase separation in rubber modified epoxies as a function of acrylonitrile content of the modifier and the temperature of cure. It was suggested that a finite time is required for rubber to separate into rubber rich domains; and the required time increases continually during cure as the viscosity of the system increases due to increasing molecular weight of the polymers. Qian et al. (1995) prepared poly (butadiene-co-styrene) core and poly(methyl methacrylate) shell using two-step emulsion polymerization to use as a toughening agent for epoxies. They found that fracture toughness was effectively doubled after modification. Dispersion of modifier particles in the epoxy system was suggested to play a significant role in toughening of epoxies, with greater degree of micro segregation of the particles in the epoxy matrix imparting greater fracture toughness to the modified epoxies.

More recently, Zheng et al. (2004) studied the rheological behavior, penetration characteristics, and fracture performance of liquid phenol-formaldehyde resole and polymeric diphenylmethane diisocyanate (pMDI) hybrid mixtures. They observed that hybrid properties are a function of simple emulsion effects. Improvement in toughness of PF matrix was significant at low pMDI levels due to dispersed urethane/urea/biuret phase; however, dispersed-PF phase resulting from addition of small quantities of PF to urethane/urea/biuret matrix did not result in a significant improvement in resin toughness.

Effect of maleated co-polymers

Maleic anhydride is extensively used in wood plastic composites (WPC) in the form of a grafted co-polymer with polypropylene or polyethylene (maleic anhydride polypropylene, MAPP; maleic anhydride polyethylene, MAPE). Maleic anhydride is speculated to form a bond between wood flour and polymer matrix enhancing the performance of the composite (Felix and Gatenholm 1991, Maldas and Kokta 1991, Stark 1999, Simonsen et al. 1998, Lu et al. 2002). Simonsen et al. (1998) found that treating aspen fiber with styrene maleic anhydride (SMA) co-polymer enhances mechanical properties of the composite and reduces moisture absorption. In addition, it was suggested that the co-polymer (SMA) forms a strong moisture barrier, though it is not completely impermeable.

Reaction of the maleic anhydride moiety with the wood

Studies have been done to observe the effect of MAPP on moisture affinity and mechanical properties of wood (Marcovich et al. 1998, Patil et al. 2000 and Felix et al. 1991). Lu et al. (2002) treated wood flour with MAPP and found primary bond formation between wood and the maleated polymer. The work also suggested that the maleated polymer is grafted on the wood surface by a succinic half-ester bridge linkage.

Clemons et al. (1992) showed there was a primary bond formation between the hydroxyl group of wood and maleic anhydride. Fiberboards made out of the maleic anhydride treated fibers showed greatly reduced reversible and irreversible thickness swelling. Irreversible thickness swelling was shown to be completely removed when the wood was treated with maleic and succinic anhydride. Same work also revealed that esterification of wood also increases ductility of fiberboard. Hartley and Schneider (1993) studied the water vapor diffusion characteristics and adsorption isotherm of sugar maple wood flour and WPC made out of the same wood. They found a decrease in cell wall moisture uptake and reduction in water vapor diffusion for the wood in WPC than in untreated wood. WPC made with maleic anhydride treated teak (*Tectona grandis*) sawdust showed a two to three fold improvement in hardness and reduced thickness swelling compared to untreated composite (Patil et al. 2000).

Snijder and Bos (2000) in their study on natural fiber thermoplastic composites found that the molecular weight of the MAPP was more of an important factor than maleic acid content for coupling efficiency. Addition of MAPP in Kudzu fiber PP composite increased the tensile strength and tensile modulus by 24% and 54% respectively due to better interfacial bonding between treated fiber and the matrix (Xiaoyu et al. 2002). However, excess of coupling agents at the interface was found to be detrimental to coupling action and may act as an inhibitor rather than a promoter of adhesion (Maldas and Kokta 1989, Snijder et al. 1997). Mechanical properties of composites increased with an increase in MAPP and reached a plateau at high MAPP levels. In a recent study Garcia et al. (2005) fabricated medium density fiberboard (MDF) from fibers treated with maleated polypropylene wax. They found a reduction in thickness swelling and water absorption with the treatment of MAPP. Same study also revealed that the modulus of elasticity, modulus of rupture and internal bond strength for the MDF increased with treatment with MAPP.

Fracture Cleavage Analysis

Fracture cleavage analysis method is widely used to investigate fracture toughness of an adhesive system. Dual cantilever beam (DCB) specimens are tested to investigate adhesive bond quality (Ebwele et al. 1986, River et al. 1989, Gagliano and Frazier 2001, Scoville 2001). Using linear elastic fracture mechanics, an energy balance is described when the DCB specimen is loaded in opening or mode I cleavage (Figure 2). Displacement energy input from the test frame is balanced against the sum of two energies: potential energy stored in DCB and energy which is required to extend an interlaminar crack. The crack extension energy is often referred to as the mode I fracture energy, G_I (fracture energy at crack initiation, G_{Ic}, and at crack arrest, G_{Ia}), as shown in Equation 1 (Blackman et al. 1991, Scoville 2001).

$$G_I = \frac{P_C^2}{2B}\frac{dC}{da}$$ Equation 1

Where,
P_c = Critical load when crack extension is initiated or arrested (N)
B = Width of the DCB (mm)
$\left(\frac{dC}{da}\right)$ = Change in compliance (C) with the change in the crack length, a, $\left(\frac{N}{mm}\right)$

As the crack length increases along the bondline in a DCB specimen, the stiffness of the beam decreases and the compliance increases. Modifications are made to take into account the change in compliance as the crack length increases. This method is termed as shear corrected compliance method (Blackman et al. 1991, Schmidt 1998, Scoville 2001, Gagliano and Frazier 2001) as in Equation 2.

$$G_I = \frac{P_C^2}{B}\frac{(a+\chi)^2}{EI_{eff}}$$ Equation 2

Where,
P_c = Critical load when crack extension is initiated or arrested (N)
B = Width of the DCB (mm)
a = Crack length (mm)
χ = Shear correction factor (see Appendix)
EI_{eff} = effective flexural rigidity of the Double Cantilever Beam specimen

This method of adhesive characterization has been used by many researchers. Ebewele et al. (1982) stated that fracture behavior, if carefully controlled using fracture mechanics principles in specimen design, could explain very complicated nature of wood bonding and be very useful for the evaluation of adhesive properties. River et al. (1989) also concluded that fracture cleavage test for crack initiation energy and crack growth rate stability provides more useful information about the behavior of adhesive than conventional shear tests.

Materials and Methods

A series of tests including, particle size analysis, resin cure kinetics and resin toughness were conducted to test the hypothesis and achieve the goal of this study. Figure 1 summarizes schematically the methodology implemented in this study to accomplish the objectives. Commercially available OSB phenol formaldehyde face resin (50% solid content), from Dynea chemicals, was used in this study. Maleic anhydride polyethylene (MAPE) and maleic anhydride polypropylene (MAPP) are commercially available in different forms. The most common forms are pellet, atomized particles (or powdered form) and emulsion form. Palette form was not considered in this study as it was necessary to have a thorough mixture of liquid phenol formaldehyde resin and MAPE or MAPP before application for a uniform distribution of additive in the resin and the composite panel. MAPE and MAPP were obtained in both solid form (20-mesh) and emulsion form (1 micron particles suspended in water). Two forms of MAPO emulsions were available, namely anionic and nonionic emulsions. The emulsifier

present in anionic emulsion was diethylaminoethanol and that for nonionic emulsion was Tomadol 25-9®. A discussion with Honeywell experts revealed that when anionic emulsion is heated at higher temperatures (> 120°C), the emulsion breaks down and the emulsifier diethylaminoetheanol disintegrates and evaporates out of the system. Therefore, when the system is cooled MAPO can not go back into an emulsion form as the emulsifier will not be present. On the contrary, in case of non-ionic emulsion of MAPO, the emulsifier Tomadol 25-9® is stable at the range of temperatures applied during OSB pressing process; therefore, in the cured system MAPO can still go back to an emulsion form. In a cured adhesive system containing anionic MAPO emulsions, MAPO will not go back into an emulsion form and, thus, would not leach out when it will come in contact with moisture. MAPE and MAPP anionic emulsions, supplied by Honeywell Specialty Chemicals, were used in this study; their properties are summarized in Table 1 (Honeywell 2005).

Table 1. Properties of MAPE and MAPP anionic emulsion used in this study.

MAPO Type	**Solid Content (%)**	**Maleic anhydride Content (%)**	**pH**	**Viscosity (cps)**
MAPE	25%	3.059%	8.5	25.6
MAPP	30%	6.992%	8.5	14.5

Atomized particle or powdered form of MAPO was also supplied by Honeywell Specialty Chemicals. Powder form of MAPE and MAPP were further pulverized to finer particles (will be discussed in the later sections). Resin formulations were prepared by thoroughly mixing MAPE or MAPP (either in particle form or in emulsion form) with liquid phenol formaldehyde resin. All formulations were prepared starting with 100 g of liquid PF resin in a 250 ml beaker. Amounts of MAPE and MAPP were calculated on the basis of solid content of PF resin and added to the beaker. The beaker was then placed on a stirrer and mixed for 15 minutes to get uniformly blended resin formulations. Same procedure was followed to prepare resin formulations for all tests as needed just prior to application. Commercially available basswood strips (1.5 mm nominal thickness and 6 mm wide) were used for DMA three point bending tests. Fracture analysis was performed with yellow poplar wood. Procedures used for each of the tasks as outlined in the objectives section will be discussed next.

Particle Size Analysis

Effect of MAPE or MAPP in the cured resin system significantly depends on how well they are distributed in the system, thus particle size plays a significant role (Romano et al. 1994). Due to limited resources it was assumed that MAPE and MAPP would have similar particle size effects, thus determination of particle size influence on the resin system, during and after cure, were investigated with only MAPP. The effects of different particle sizes of MAPP in atomized form (80-mesh, 100-mesh and 200-mesh) and in emulsion form were compared. Scanning electron microscopy (SEM) was used to observe the distribution of MAPP particles in the cured resin system. The effect of different particle size on the dynamic properties during cure was monitored using dynamic mechanical analysis (DMA).

Determination of Particle Size Distribution

Commercially available atomized MAPP averaged a particle size of 20-mesh (0.841 mm). As the goal was to achieve a good distribution of MAPO particles in the resin as it would facilitate better phase separation, thus imparting more toughness to the resin system. Particles were further ground in a Wiley mill grinder followed by a ball mill grinder to reduce particle size to less than 80-mesh (0.177 mm). Three different particle sizes were examined to study the influence on MAPO distribution in the resin: 80-mesh, 100-mesh (0.149 mm) and 200-mesh (0.074 mm). As for MAPP anionic emulsion, size of the particles was 1 micron. Particles were separated through standard wire meshes as per ASTM E11 (ASTM 2004). Light scattering particle size analysis was performed using AccuSizer®780 automatic particle size analyzer to determine the actual distribution of particle sizes in each mesh size batch.

Distribution of MAPO in the Resin

Scanning electron microscope (SEM) was used to observe cured specimens of resin blends. Specimens were prepared by thoroughly mixing liquid phenol formaldehyde resin with MAPP (particles or emulsion) to make an adhesive formulation of PF and 1.5% MAPP. The mixtures were then poured in petri dishes and kept in ambient temperature for 48 hours to allow evaporation of water from the resin. The dishes were put into the oven at 145 °C for 30 minutes to get complete cure of the adhesive system. SEM specimens were prepared from these cured resin specimens and examined at varying magnifications ranging from 50x to 1000x.

Effect of Particle Size on Storage Modulus of Cured Resin Blend

Effect of MAPO particle size in resin blend on the storage modulus was investigated using DMA. Mixture of PF and 0.5% MAPP, both in emulsion form and particle forms (80 mesh, 100 mesh and 200 mesh) were tested in three point bending in DMA. Sample preparation and testing procedure followed are the same as described at later part of this chapter. Dynamic moduli (storage modulus, loss modulus and tanδ) were recorded during the curing process. Percentage increase in storage modulus (E') during cure of different formulations was observed and compared. Based on the results of specific objective 1, as will be discussed later, emulsion form of MAPO was found to be more effective than powder form in blending with the PF resin and yielding a uniform distribution of MAPO particles in the resin; therefore, in the next two tasks only MAPO emulsions were examined in investigating whether to blend MAPE or MAPP with PF resin in manufacturing OSC test specimens (Chapter3).

Determination of Curing Parameters of Resin Blends

Differential Scanning Calorimetry was used to determine the curing parameters, namely curing temperature and curing time, of the resin blends. The intent was to investigate any changes in curing parameters of the PF thermoset resin system due to addition of MAPO emulsions because application of proper curing parameters is very important to cure the adhesive systems completely before comparing their properties. It was also assumed that MAPP and MAPE anionic emulsions had similar behavior in terms of curing temperature and curing time when mixed with PF resin. Based on discussions with Honeywell Specialty Chemicals, it was

understood that these two emulsions had similar chemical composition except for the fact that MAPE and MAPP had different melting temperatures (melting point of MAPE around 110°C and melting point of MAPP is around 140°C). It is believed that in the emulsion form the melting of MAPP and MAPE would not change significantly; and, as MAPP has higher melting temperature, determination of curing temperature and time of PF and MAPO blends was assumed to be controlled by MAPP. Therefore, curing time and temperature were determined for PF + MAPP emulsions and same curing parameters were applied for curing of PF + MAPE emulsion.

Neat PF resin and blend of PF and anionic emulsion of MAPP at 6% level were dynamically ramped in Metlar-Toledo 822^e DSC from 25 °C to 200 °C at a ramping rate of 5 °C/min. High pressure sealed gold plated 30µL pans were used for these tests. Results were compared to see if there was any change in the curing parameters due to addition of MAPP. The temperature at which the reaction rate became highest was monitored. It was observed that at 135°C the reaction rate becomes highest. Thus, 145°C was chosen as the curing temperature to ensure that complete curing of the resin blends was obtained.

Curing time was then determined in a two-step process. First, resin specimens were isothermally cured in the DSC cell at 145°C for varied periods of time, ranging from 0.5 min to 2.5 min with an increment of 0.5 min. After curing for the specified time, the resin samples were promptly plunged into ice water to arrest the reaction. This step was then followed by dynamic ramping of the cured samples from 25 °C to 220 °C at a ramping rate of 5°C /min. The residual heat of curing (h) for all the specimens was recorded. The extent of cure (α) was then calculated as a percentage of the total heat of cure (H) using Equation 3 (Wang et al. 2005),

$$\alpha(\%) = \frac{H-h}{H} \times 100 \qquad \text{Equation 3}$$

Effect of MAPO on Resin Properties

Effect of MAPO on resin blend properties, namely stiffness and toughness were evaluated using DMA and fracture analysis. Molecular level changes, interactions and energy dissipation were monitored using DMA whereas; fracture analysis investigated the effect of phase separation, due to addition of MAPO, on resin blend toughness. Three point bending specimens were tested in DMA to investigate the effects of MAPO on the dynamic properties of resin. Dynamic properties of laminates bonded with different resin blends were tested during and after curing. Mode I fracture cleavage tests were performed to evaluate and compare the effects of MAPO on the fracture toughness of the resin system.

Dynamic Properties of Specimens during and after Cure

Test specimens were prepared from commercially available basswood strips. Strips were cut to a length of 52 mm. Nominal width and thickness of the strips were 6 mm and 1.5 mm, respectively. The pieces obtained were then conditioned to 12% MC. After conditioning, resin blends were applied on one side of each strip to sufficiently form a uniform thin layer, and two strips were then used to form a laminate with the resin layer in the middle. The laminates were

then gently pressed to squeeze out the excess resin and wiped off. It was found from the first few test runs that 11% resin content on the basis of wood weight was sufficient to form a uniform thin layer of resin. Therefore, for rest of the tests 11% resin content was used to form the laminates.

The resin blends tested were, neat PF and PF blended with 0.5%, 1.5% and 6% MAPE and MAPP anionic emulsion. Three replicates for each blend were tested. Laminates were put into a Rheometric II DMA chamber and subjected to three point bending. The frequency of testing was set to 1 Hz. Determining the strain level to conduct the tests at was vital to ensure that the test was always in the linear viscoelastic range of the specimen. The stiffness of laminates changed with temperature as at higher temperature resin curing took place. Therefore, dynamic strain sweep test was performed with the laminates at different temperatures to determine the linear viscoelastic region throughout the test. A strain of 2×10^{-5} was found to be suitable to keep the test within linear viscoelastic region for entire range of temperature. The temperature of the DMA chamber was ramped from 25 °C to 180 °C at a ramping rate of 2 °C/min. Dynamic moduli (E' and E'') and $\tan\delta$ were compared.

Laminates with different adhesive blends were tested in two steps. First, laminates with uncured resin blends were subjected to the testing schedule mentioned previously and the changes in dynamic moduli were observed during resin curing process. In the second step, cured laminates were then conditioned to 12% MC, and then were subjected to the same testing schedule as previous step. Changes in the dynamic moduli and $\tan\delta$ were monitored during the test.

Fracture Cleavage Analysis

Rectangular blocks of dimensions 300mm x 200mm x thickness of the lumber were cut from yellow poplar lumber. The blocks were then edged in a jointer to clearly determine the grain direction. Using a band saw the blocks were then sliced along the thickness to get 16-17 mm thick plates while maintaining approximately 5° grain angle with the longitudinal axis. The plates were then planed to a thickness of 12 mm and placed in the conditioning room to equilibrate to 12 % MC. Prior to resin application after conditioning, the plates were re-planed to a final thickness of 10 mm.

Resin blends were applied uniformly on the bonding surface. Plates were weighed before and after resin application to determine the amount of adhesive applied. A continuous layer of resin was applied on the surface. It was found that 4% liquid resin on the basis of weight of the wood plates resulted in a uniform layer of resin. All plates were bonded by applying 4% resin on the basis of weight of the wood plates. A 35mm wide Teflon® film was placed at the end of the bonding surface to refrain that portion from bonding. This portion that was not bonded would then act as the pre-crack in the fracture specimens. Thickness of the Teflon® film was less than 13μm as suggested by Kinloch (2000). Specimens were pressed in a hot press to bond the matched plates together with different resin blends. Pressing schedule was maintained such that the adhesive layer between the two wood panels reached 145°C and was held for 5 minutes to ensure complete cure of the adhesive (these parameters were determined based on DSC results discussed previously). A uniform pressure of 550 Kpa (80 psi) was maintained to bond the

plates together. After pressing, the laminates were cooled, cut and trimmed into 20 mm wide and 200 mm long DCB specimens (Figure 2).

Two holes of 3 mm diameter were drilled 10 mm from the ends of each DCB specimens (Figure 2). A thin coat of white water based correction fluid was applied on the bond line at least 24 hrs before testing. A photocopy of millimeter ruler was glued onto the side of the test specimens to measure the crack length during the test.

Number of replicates for each resin blend was determined by one-factor response design, generated using Design-Expert® (Stat-ease 2006) software to limit the number of tests conducted to obtain statistically valid results. Neat PF and PF with anionic emulsion of MAPE and MAPP were tested. Proportion of MAPE and MAPP varied within lower and upper limits of 0 and 6 percent based on weight of the PF resin (100% solids). Prepared specimens were subjected to two environmental conditions: 12% MC and 24-hr water soak. In the one-factor design, MAPO content was considered as a numeric factor and the environmental conditions (12% MC and 24 hours water soak) and type of MAPO (MAPE and MAPP) were considered as categorical factors. Response variables were crack initiation (G_{Ic}) and crack arrest (G_{Ia}) energy values. Initial design suggested 36 runs. Additional replications were added to make the design more robust.

Fracture Testing Methodology

Fracture tests were conducted according to the protocol suggested by previous studies (Gagliano and Frazier 2001, Scoville 2001, Blackman and Kinloch 2000). Tests were conducted at a loading rate of 1 mm/min. With the drop in load upon crack initiation, the cross head was programmed to hold the position at 5% load drop for one minute. At the end of one-minute period, when a quasi-stable load state was reached, crack length, corresponding crack arrest load and displacement were recorded. Photographs were taken with a high-resolution digital camera to measure crack lengths. After recording the data, the cross head was returned to the starting point and the next cycle was started. These cycles were repeated until the crack tip exceeded 150 mm mark on the paper ruler or the specimen failed by propagation of the crack through the length of the specimen. Figure 3 shows a typical load versus displacement plot for a fracture specimen. The test was carried out with a 5500 series Instron® universal testing machine controlled by Bluehill® software.

Fracture energies were calculated using shear corrected compliance method as discussed previously (Blackman et al. 1991, Gagliano and Frazier 2001, Scoville 2001). A plot of crack length and the corresponding cube root of compliance was generated. Slope (m) and intercept (b) were determined from the plot. The shear correction factor (χ) is the ratio of intercept (b) to the slope (m). The crack initiation energy (G_{Ic}) and crack arrest energy (G_{Ia}) were calculated using Equations 4 and 5 respectively (Blackman et. al. 1991, Gagliano and Frazier. 2001, Scoville 2001).

$$G_{Ic} = \frac{P_C^2}{B}\frac{(a+\chi)^2}{EI_{eff}} \qquad \text{Equation 4}$$

Where,
a = Crack length (m)
P_c = Critical load for crack initiation (N)
B = Width of the specimen (m)
χ = Shear correction factor, $\chi = \frac{b}{m}$, (m)
EI_{eff} = Effective flexural rigidity of the Double Cantilever Beam specimen, $EI_{eff} = \frac{2}{3m}$

$$G_{Ia} = \frac{P_a^2}{B}\frac{(a+\chi)^2}{EI_{eff}} \qquad \text{Equation 5}$$

Where, P_a is the critical load at crack arrest.

Results and Discussion

Particle Size Analysis

Figures 4 to 6 show the volume percentage distribution of particle diameters for 80, 100 and 200-mesh batches of MAPP in dry particle form obtained by light scattering particle size analyzer (AccuSizer® 780), respectively.

Distributions indicate that every batch consisted of a wide range of particle diameters. Considering the maximum volume percentage in each batch, 80-mesh (Figure 4) and 200-mesh batches (Figure 6) had comparable or slightly smaller size to the targeted values than 100-mesh batch (Figure 5) where greater number of particles was finer than targeted size. Significant proportions of finer particles were expected as particles were ground in a ball mill, where there is limited control on the process. It was especially difficult to reduce MAPP and MAPE particles as they were more malleable and did not break down into finer particles even after extended periods of processing in the ball mill. In the rest of the report, we will refer to the batches as 80-mesh, 100-mesh and 200-mesh.

Distribution of MAPP in Resin Blends

Scanning electron microscopy (SEM) of cured resin blends of PF and 1.5% MAPP (blended in the form of dry particles and emulsion) clearly showed distinct differences in distribution and surface topography as we vary the particle size. SEM pictures of cured resin formulation consisting 80-mesh, 100-mesh, 200-mesh particles and MAPP anionic emulsion are shown in Figure 7.

Emulsified MAPP clearly yielded the most uniform distribution in the PF resin. The surface qualities were found to get better as finer particles were used. Larger particles (80-mesh and 100-mesh) resulted in more agglomeration or clumping of particles and was harder to achieve a uniform distribution (Figure 7a and 7b). SEM pictures of formulation with PF and MAPP anionic emulsion (particle size of 1 micron) showed better distribution of MAPP in the resin,

even at a higher magnification (Figure 7d). Even the surface topography was much better and uniform when MAPP anionic emulsion was used.

Dynamic Properties of Resin Blends

Storage modulus (E') during the cure process with MAPP solid particles as well as emulsion was compared as a measure of stiffness of the laminates. Figure 8 shows the comparison of percentage increment in E' for different formulations during cure.

Even though PF resin with MAPP in all forms yielded higher percentage increase in storage modulus, comparison of percentage increment in E' during cure did not show a significant difference between the formulations with different MAPP solid particle sizes and emulsion (p-value = 0.168). From this analysis, it could be inferred that though the storage modulus of the resin blends was not greatly influenced by different particle sizes (Figure 8), the distribution of MAPP in the blend was significantly improved with finer particles.

Considering the ease of application during manufacturing of oriented strand composite panels, liquid MAPP emulsion with particle size of one micron would be much easier to apply and would yield a better mixture than solid MAPP particles. Therefore, further analysis on cure kinetics of resin blends using DSC and efficacy of blending MAPP or MAPE in PF resin to improve its toughness and moisture resistance with DMA and fracture cleavage test were conducted only on blends with MAPO anionic emulsions.

Curing Parameters of Resin Blends

DSC analysis under temperature ramping of uncured PF resin and PF and MAPP anionic emulsion blend showed an exothermal peak at 135 °C (Figure 9).

The peak temperature did not change between neat PF resin and formulation with PF and 6% MAPP anionic emulsion. To ensure complete cure, the curing temperature for all the formulations was fixed at 145°C. From this graph the total heat of cure was calculated. This was done by integrating the curve from the onset to end point of the exothermal peak. The total heat of cure was then normalized for heat of cure per gram of resin. The values of normalized heat of cure from different formulations were found to be quite close to each other (Table 2).

Table 2. Comparison for average normalized heat of cure for neat PF and PF with 6% MAPP emulsion.

Blend	**Average Normalized Heat of Cure (J/g)**	**CoV (%)**
Neat PF	99.5	4%
PF + 6% MAPP	101.7	5%

Formulations cured at 145°C for different time periods were then dynamically ramped to determine residual heat of cure. Normalized heat flow vs. temperature plots for mixture of PF and 6% MAPP anionic emulsion cured at 145°C for different time periods are shown in Figure 10. The residual heat of cure (h) was calculated for each of the cured samples by integrating the

residual exotherm curve. The extent of cure (α) was then calculated using Equation 3. It was found that 2.5 minutes at 145°C resulted in 98% cure of the resin formulation (PF + 6% MAPP). The endothermic peaks at 100°C represent evaporation of water. It was mentioned by earlier researchers (Vick and Christiansen1993) that with the use of high pressure sealed pans it was not possible to observe the secondary processes like evaporation of water. However in this case lower magnitude of residual heat of cure for uncured resin was not much higher in magnitude than the heat flow for evaporation of water. Therefore, both the processes were significant and were observed during temperature scan. This was validated by the temperature scan of cured specimens after drying; endothermic peaks were not present for dried specimens, justifying the fact that these endothermic peaks were indeed due to the evaporation of water.

Effect of MAPO on Resin Properties (Dynamic Mechanical Properties and Fracture Toughness)

Dynamic Mechanical Analysis

Dynamic mechanical analysis was employed during and after curing to investigate the effect of MAPO on the adhesive blend properties. Influences of the addition of MAPO in PF resin were investigated at molecular level in this method. During the curing process, as the temperature was ramped, the stiffness changes in the sample were monitored. Figure 11 shows a typical trend of percent increase in storage modulus (E′) during the curing process.

Storage modulus (E′) of the laminates remained fairly constant until the resin started curing at the temperature range of 80 °C to 100 °C, after which the stiffness modulus values increased, reached the maximum and leveled off. This is a typical curing trend for thermoset resin (Menard 1993, Lisperguer et al. 2005). At the onset of curing, cross linking of resin starts and as it increases and ultimately becomes a cross-linked giant molecule of cure resin, the stiffness of the laminate also increases. Percentage increases in the stiffness values during the curing process were then calculated from the initial storage modulus (E′) and maximum storage modulus (E′). The maximum average percentage increase in the stiffness modulus (E′) values for specimens with neat PF and specimens with the mixture of PF and different MAPO anionic emulsions during the curing process were compared in Figure 12.

Addition of MAPP anionic emulsion was found to increase the laminate stiffness of the resin system during cure, though the increase was not significant. Addition of MAPE anionic emulsion into PF also showed an improvement in E' during the curing process, however there was much higher variations in the results. Analysis of variance indicated that the differences between the formulations were not statistically significant (p-value = 0.0764). However, it was evident from the results that the addition of MAPP or MAPE did not decrease the resin stiffness as it cured due to addition of thermoplastic co-polymer. This is a positive outcome as the investigators would like to improve the resin toughness without adversely effecting resin stiffness with addition of MAPO (MAPP or MAPE) anionic emulsions in the resin system.

Parameter tanδ is a measure of energy dissipation or damping of a polymer. A typical trend of tanδ for resin blends tested is shown in Figure 13. Two distinct peaks can be noticed. The first peak was obtained at about 60 °C and the second one was found in the vicinity of 120°C.

Previous studies also observed a similar trend (Geimer et.al. 1990, Lisperguer et.al. 2005). The peak at lower temperature is termed as the gelation point where the monomers rapidly start forming network structure and the viscosity of the system dramatically increases. At this point the system transforms from sol state to gel state (Turi 1981, Craver 1983). The second peak is the vitrification point, where the polymer reaches a rigid network of infinite molecular weight and transforms from rubbery to glassy state. This usually happens at the glass transition temperature of the polymer (Turi 1981, Craver1983). The trend of tanδ showed that with the addition of MAPO into the mixture the transition of adhesive systems from sol to the gel state and from there to the vitrified state did not change significantly.

As indicated in the procedures, a follow-up analysis with DMA was performed with the cured laminates to determine the effects of MAPO on the damping property of the cured resin systems. A typical trend of storage modulus (E') and tanδ when cured specimens were ramped from 25°C to 180°C at 2°C /minute rate, is shown in Figure 14. Storage modulus of the sample starts to increase from about 80 °C and reaches a maximum at about 100 °C. It was assumed that this increase was due to the loss of moisture during the temperature ramp. Similar test with dry specimen was conducted to confirm this assumption. It was found that with dry specimen the storage modulus was constant throughout the temperature ramp, confirming that the increase in stiffness was due to loss of moisture.

The effect of different formulations on the damping property of the cured resin system was investigated by examining the normalized tanδ of the specimens at three different temperatures, 35 °C, 40 °C and 45 °C. These values were obtained by normalizing storage (E') and loss moduli (E") values on the basis of initial E' and E" values of uncured laminates and calculating tanδ based on them (tanδ = E'/E"). Because fitting a polynomial to tanδ values at specified temperatures did not yield good predictive model, discrete values from the experimental data at specified temperatures (35 °C, 40 °C and 45 °C) were compared. Comparison of normalized (for uncured laminate moduli) tanδ for cured formulations with PF and different proportions of MAPO (MAPE and MAPP) at 40°C is shown in Figure 15. Similar trends were observed at 35 °C and 45 °C.

Comparison of data indicates there is a distinct increase (~ 35% increase) in the tanδ value with the addition of small amount (0.5%) of MAPE into the system. On the other hand addition of MAPP showed no improvement. Comparison of mean test at 0.05-significance level indicated that formulation with 0.5% MAPE was statistically significant than other formulations; however, MAPP and PF values did not differ significantly at any other levels. As MAPP levels increased tanδ of the specimens showed an increasing trend. One of the hypotheses of this study was with the addition of MAPO into resin blend the damping property should increase. Use of MAPE followed the hypothesis at lower proportion, but MAPP did not. This fact can be justified from the structural differences in MAPE and MAPP polymers. Addition of more flexible MAPE might have contributed in damping improvement, whereas addition of MAPP did not show significant difference in damping property. It should be kept in mind that DMA results are sensitive to specimen size and variations in wood from specimen to specimen. It is difficult to isolate the behavior of resin and examine the changes in resin damping property as blend compositions are changed. Thus, fracture cleavage analysis was also performed in an attempt to investigate differences in energy dissipation of fractured glue lines as resin blends were changed.

Fracture Cleavage Analysis

Fracture energies for dual cantilever beam (DCB) specimens were calculated. Tables 3 and 4 summarize average values and coefficient of variations (COV) of G_{Ic} and G_{Ia} for specimens with different formulations at 12% moisture content.

Table3. Average G_{Ic} and G_{Ia} values for PF + MAPE adhesive formulations at 12% MC.

Blend	Number of Replicates	Avg. G_{Ic} (J/m^2)	COV (%)	Avg. G_{Ia} (J/m^2)	COV (%)
Pure PF	4	86	17	61	24
PF+ 1.5%MAPE	4	69	15	54	22
PF+ 3.0%MAPE	5	74	14	60	15
PF+ 4.5%MAPE	2	46	-	29	-
PF+ 6.0%MAPE	4	56	37	36	40

Table 4. Average G_{Ic} and G_{Ia} value for PF + MAPP adhesive formulations at 12% MC.

Blend	Number of Replicates	Avg. G_{Ic} (J/m^2)	COV (%)	Avg. G_{Ia} (J/m^2)	COV (%)
Pure PF	4	86	17	61	24
PF+ 1.5%MAPP	3	120	37	94	39
PF+ 3.0%MAPP	6	109	30	76	40
PF+ 4.5%MAPP	3	109	21	75	41
PF+ 6.0%MAPP	5	75	22	54	21

One factor response model indicate a decreasing trend in crack initiation energies with increasing proportion of MAPE anionic emulsion in the resin blend; however, with increasing MAPP content in the resin blend, crack initiation energy increases initially, reaching a maximum at 3% level and starts to decrease with further addition of MAPP.

Reduction of crack initiation and crack arrest energies were larger at higher proportions (4.5% and 6%) of MAPE in the resin system. Analysis of variance for the model showed that MAPE and MAPP significantly effected fracture energies at 12% moisture content ($p<0.0001$). Figure 16 shows the comparison of fracture energies for varying levels of MAPE at 12% MC. Results of comparison of means at significance level of 0.05 are also shown in the figure; results with similar letters indicate no statistically significant difference.

Addition of MAPP anionic emulsion improved the fracture energies of adhesive formulations at lower levels (1.5% and 3%); beyond this point the effect leveled off or reduced. Comparison of fracture energies at varying MAPP levels is shown in Figure 17 along with comparison of means test results at significance level of 0.05.

There was an increase of 41% in average G_{Ic} value for formulation with 1.5% MAPP compared to neat PF formulation; comparing same formulations, G_{Ia} increased by 53%. This trend could

also be related with the previous works conducted on wood plastic composites, where with the addition of modifier the mechanical properties improved; however, addition of additive at higher proportions yielded no significant effect and even had a negative influence (Maldas et al. 1989 and Snijdar et.al. 1997). Similar trends were also found by previous researchers, where the addition of modifier at lower levels improved the mechanical properties of the adhesive system but the addition at higher proportions either did not have a significant effect or, in some cases, deteriorated the properties (Maldas et al. 1989 and Snijdar et.al. 1997). A comparison of means test at 0.05 significance level showed that crack initiation energy at 1.5% and 3% MAPP levels were significantly better than other MAPP levels.

Fracture toughness tests of specimens after 24 hr water soaking indicated that specimens bonded with neat PF increased. This trend was also observed by previous researchers (Scoville 2001). DCB fracture specimens were fabricated with their grain orientations at 5° angle with their longitudinal axes (Figure 2). This specific grain orientation was preferred to keep the propagating crack within the bondline; however, this would also generate a lot of stress in the bonded specimens due to difference in shrinkage and swelling patterns of two adherents during 24-hr water soak. Under soaking, specimens release stress and fracture toughness increases (Scoville 2001). Difference in shrinkage and swelling pattern within bonded specimens also caused failure of some specimens after 24 hr soak. Tables 5 and 6 summarize the fracture toughness values for 24-hr soak specimens.

Table 5. Average fracture toughness energies for formulations with MAPE after 24-hr soak.

Blend	Number of Replicates	Avg. G_{Ic} (J/m^2)	COV (%)	Avg. G_{Ia} (J/m^2)	COV (%)
Neat PF	4	113	12	86	17
PF+ 1.5%MAPE	3	60	46	44	50
PF+ 3.0%MAPE	5	44	37	34	48
PF+ 4.5%MAPE	2	42	-	36	-
PF+ 6.0%MAPE	5	57	19	44	21

Table 6. Average fracture toughness energies for formulations with MAPP after 24-hr soak.

Blend	Number of Replicates	Avg. G_{Ic} (J/m^2)	COV (%)	Avg. G_{Ia} (J/m^2)	COV (%)
Neat PF	4	113	12	86	17
PF+ 1.5%MAPP	3	65	43	50	35
PF+ 3.0%MAPP	5	161	24	119	44
PF+ 4.5%MAPP	2	89	-	52	-
PF+ 6.0%MAPP	4	44	10	34	15

One factor response plot model demonstrates a decreasing trend in fracture energy with increasing MAPE anionic emulsion content for 24-hour water soak specimens; whereas, with addition of MAPP in the blend, fracture energy dropped initially but seem to increase again maximizing at around 3% level and then decrease again at higher levels. It should be noted that coefficient of variations are relatively high indicating the complexity involved in crack

propagation through adhesive bond layer between wood substrates. Figure 18 represents the plot of fracture toughness of formulations with MAPE anionic emulsion after 24-hr water soak.

Fracture energies (both G_{Ic} and G_{Ia}) were considerably decreased with the addition of MAPE into the system. As MAPE content was increased from 0 to 1.5% a drop of 46% in the crack initiation energy and 49% in the crack arrest energy were observed. Comparison of means test at significance level of 0.05 indicated a significance difference between neat PF and other formulations with MAPE additive irrespective of the amount added; test indicated no significant differences among the PF formulations with MAPE blended in. Comparing G_{Ic} and G_{Ia} for the formulations with MAPP anionic emulsion, a 43% increase in the G_{Ic} and a 38% increase in G_{Ia} was observed for formulation with 3% MAPP (Figure 19). As for other formulations, the fracture cleavage energies were less than that of specimens with neat PF. Comparison of means test at significance level of 0.05 indicated differences in formulations; however, fracture toughness of specimens bonded with neat PF were not significantly different than those of PF with 3% MAPP (Figure 19).

Fracture toughness test results indicated different trends than DMA results. DMA showed addition of MAPE at lower proportion significantly improved the damping property, whereas, addition of MAPE decreased fracture toughness. This partially follows the hypothesis that addition of MAPO would improve the damping and toughness. At molecular level due to more flexible nature of MAPE polymer the energy dissipation was higher than blend with MAPP, but in fracture testing we characterized the wood-adhesive interphase. It could be possible that addition of MAPP resulted in a more uniform phase separation, which improved the fracture toughness of the adhesive blend more efficiently than addition of MAPE.

Trends in the results of one factor response models indicated that under both the environmental conditions (12% MC and 24-hr soak) MAPP adhesive formulations performed better than MAPE adhesive formulations. Fracture energy results indicate that effect of MAPP anionic emulsion in resin blend seems to maximize at 3% level yielding in improved fracture toughness under both 12%MC and 24-hr soak conditions. Addition of MAPE anionic emulsion seems to decrease fracture toughness of PF resin blends at even low levels and, eventually, leveling off at higher levels. One possible reason for better performance with MAPP could be because of differences in physical properties of the two co-polymer coupling agents (Table 1). MAPP anionic emulsion had higher solid content, percent of maleic anhydride content, and lower viscosity than MAPE, thus imparting better properties to the resin blends. High coefficient of variation was also observed with all fracture data. This trend was also observed by the previous researchers (Schmidt 1998, Scoville 2001, Gagliano and Frazier 2001). It was speculated that the inherent variation in the wood substrate made this process complex in nature and resulted in higher variations in the results.

Conclusions

Objectives of this study were to investigate the influence of MAPO (Maleic Anhydride Polyolefin) mixed in PF resin on the toughness of the adhesive system, to find the optimum particle size of MAPO to mix with PF and to determine the curing parameters of the adhesive blend. The findings of this study are:

- MAPP in emulsion form than in dry particle form results in a uniform distribution within a cured PF resin system leading to better phase separation.
- Particle size of MAPO did not have a significant effect on the dynamic stiffness property of cured resin blends.
- DSC analysis indicated that 2.5 minutes at 145°C resulted in 98% curing of PF and MAPP resin blend.
- DMA analysis indicated an improvement in dynamic stiffness moduli of resin blends with MAPP at lower proportions; whereas, addition of MAPE at lower proportions improved the damping property of cured resin blends.
- Fracture toughness tests showed an improvement in fracture energy of resin blends at lower proportions of MAPP (1.5 to 3% of the resin weight) in specimens conditioned to 12% MC; whereas, after 24-hr water soak treatment, resin blends with 3% MAPP showed an improvement in fracture energy.

Based on the results of this study, it can be concluded that emulsion form would perform better than particle form of MAPO if considered for application in producing oriented strand panels because of better distribution in the cured adhesive system and ease of application. MAPP was found to perform better in improving dynamic stiffness and did not have any adverse effect on the damping property of the cured resin systems. Fracture energies were also improved with the addition of MAPP than MAPE in the resin system, both at 12% moisture content and after subjecting to 24-hr water soak. Therefore, MAPP anionic emulsion will be chosen over MAPE anionic emulsion to blend with PF resin in manufacturing oriented strand composite (OSC) panels in the second part of the study where effect of adding MAPO to PF resin on physical and mechanical properties of OSC test panels will be evaluated.

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Figures

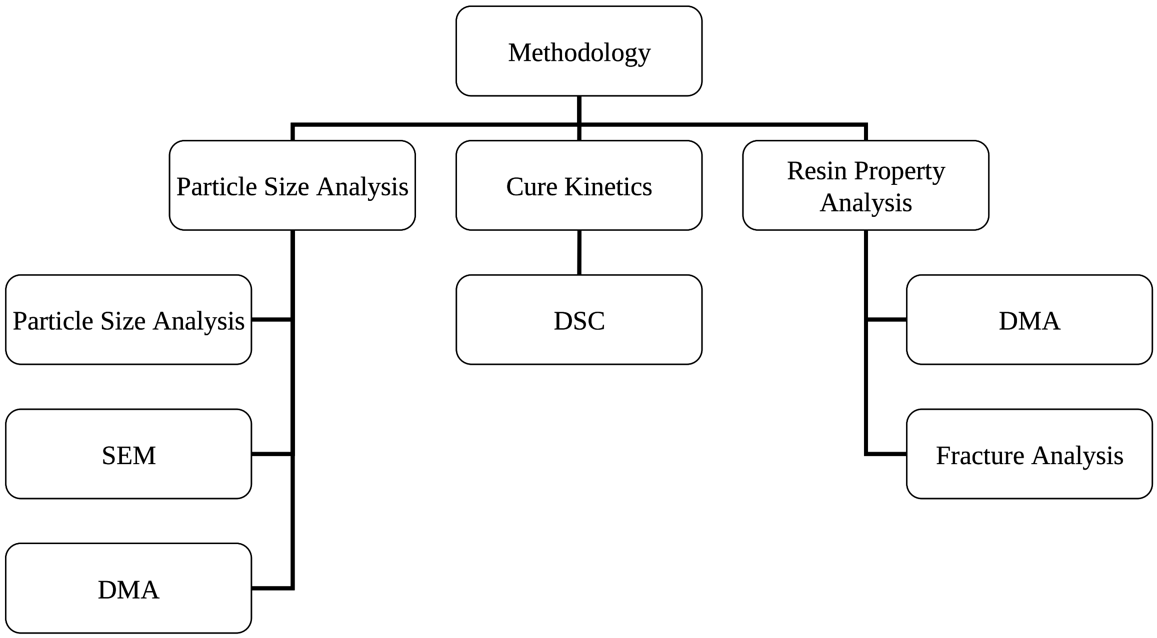

Figure1. Flow chart for the study methodology.

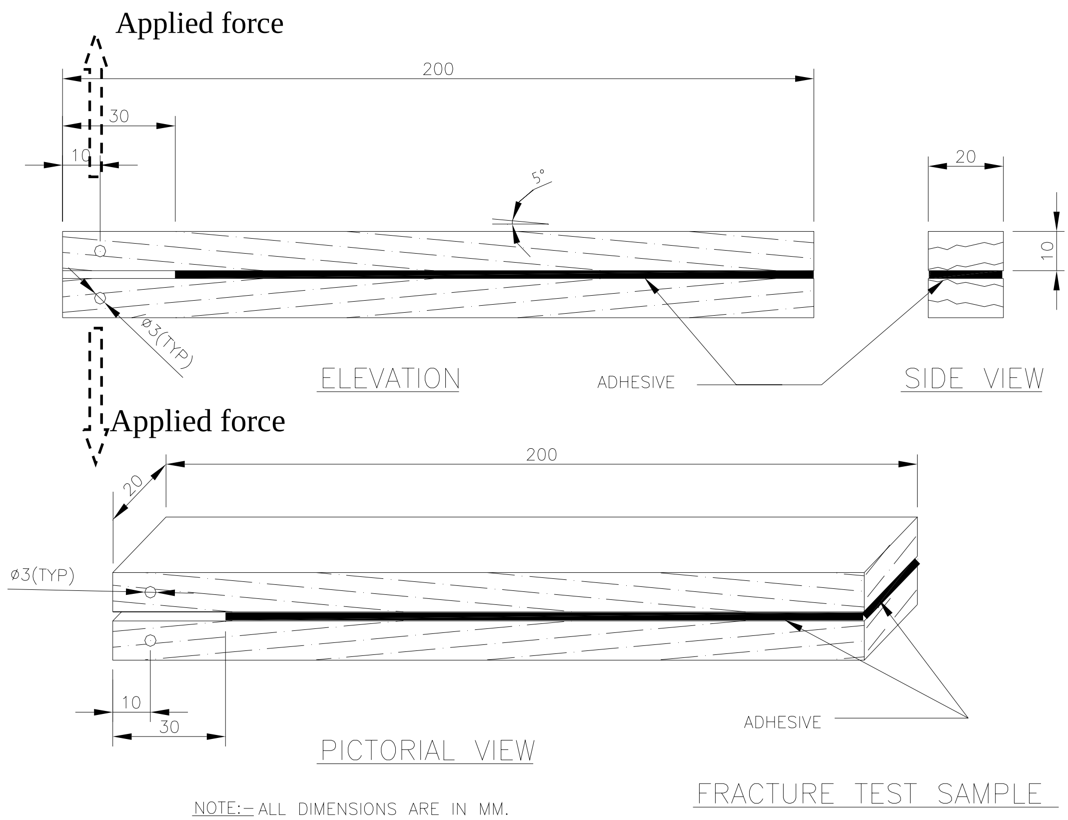

Figure 2. Dimension of fracture cleavage test specimen for Mode I fracture.

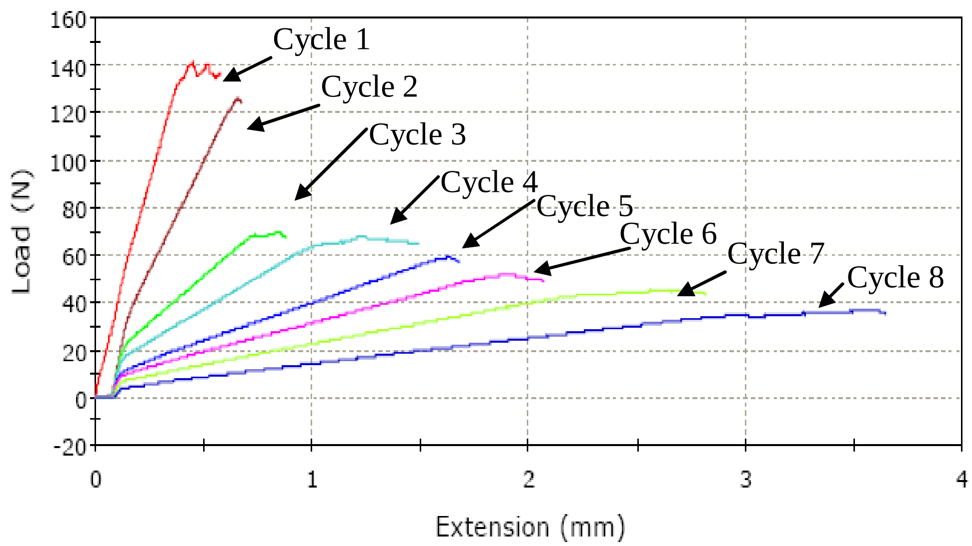

Figure 3. Typical plot of load versus extension for single fracture specimen at repeated load cycles.

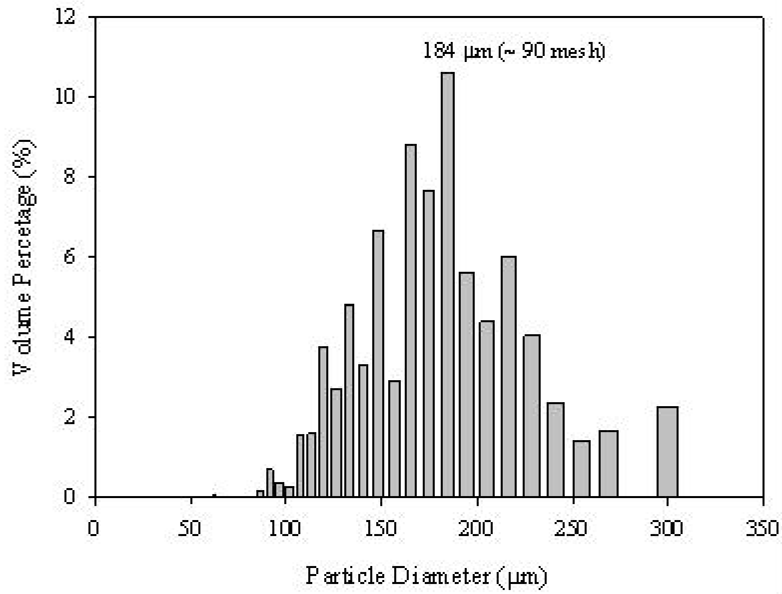

Figure 4. Actual particle size distribution for 80-mesh MAPP batch obtained using light scattering particle size analyzer.

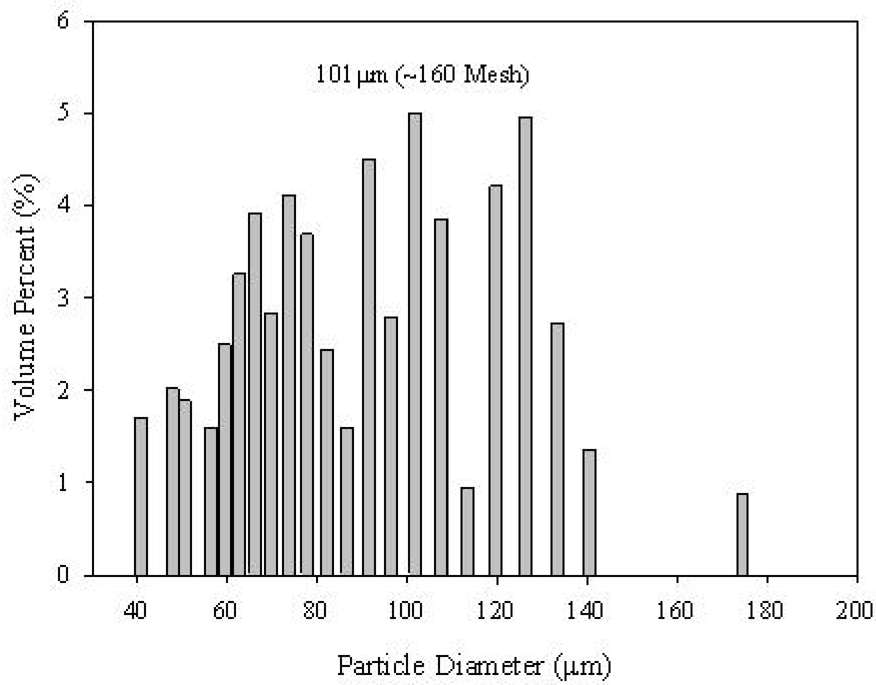

Figure 5. Actual particle size distribution for 100-mesh MAPP batch obtained using light scattering particle size analyzer.

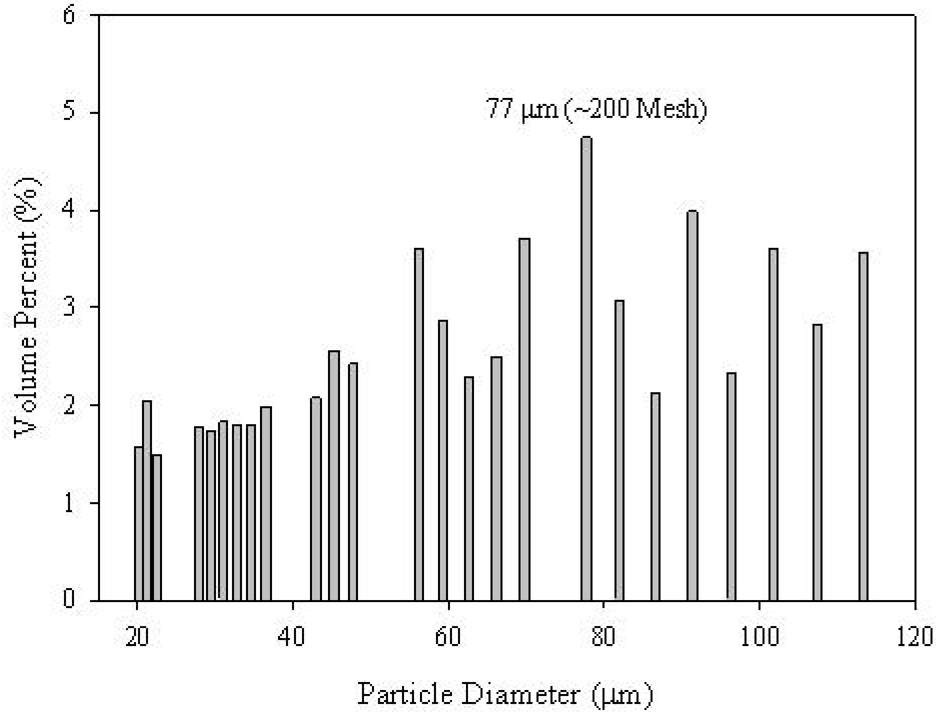

Figure 6. Actual particle size distribution for 200- mesh MAPP batch obtained using light scattering particle size analyzer.

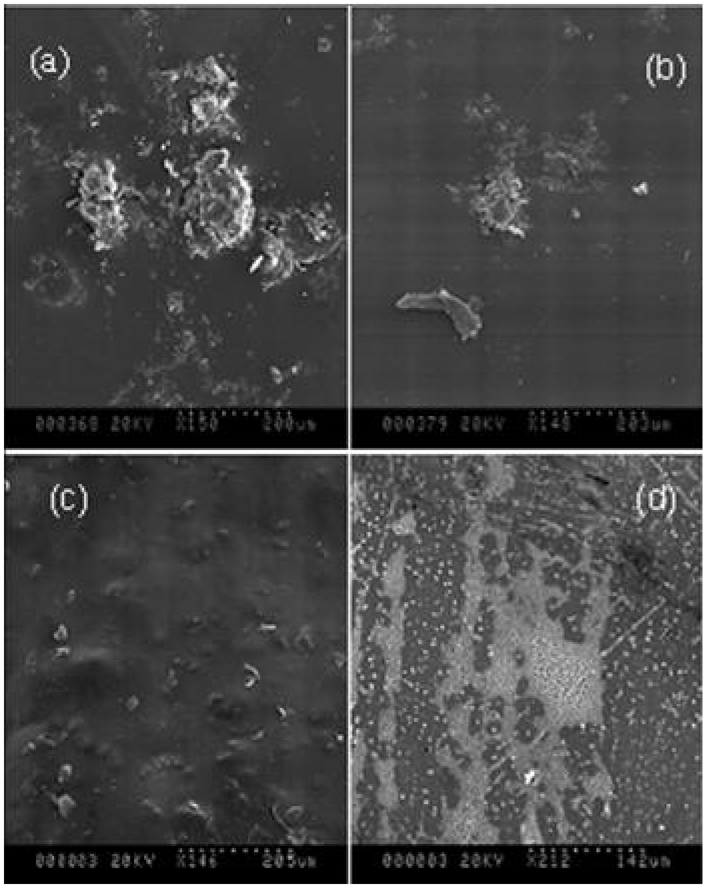

Figure 7. SEM pictures for cured adhesive formulations with MAPP (a) PF+80 mesh MAPP, (b) PF + 100mesh MAPP, (c) PF + 200 mesh MAPP and (d) PF + MAPP anionic emulsion.

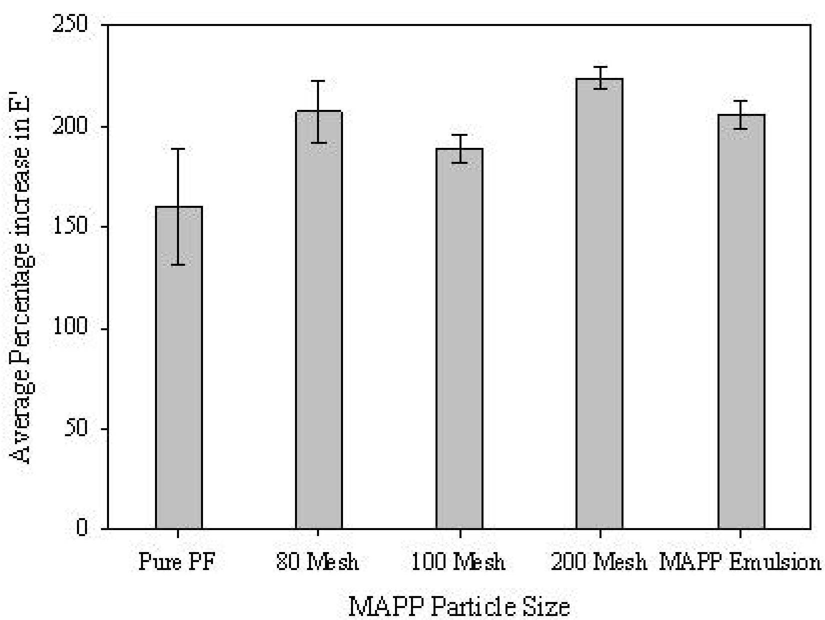

Figure 8. Comparison of percentage increase in E' using DMA during cure of blends with different forms of MAPP particles in PF resin.

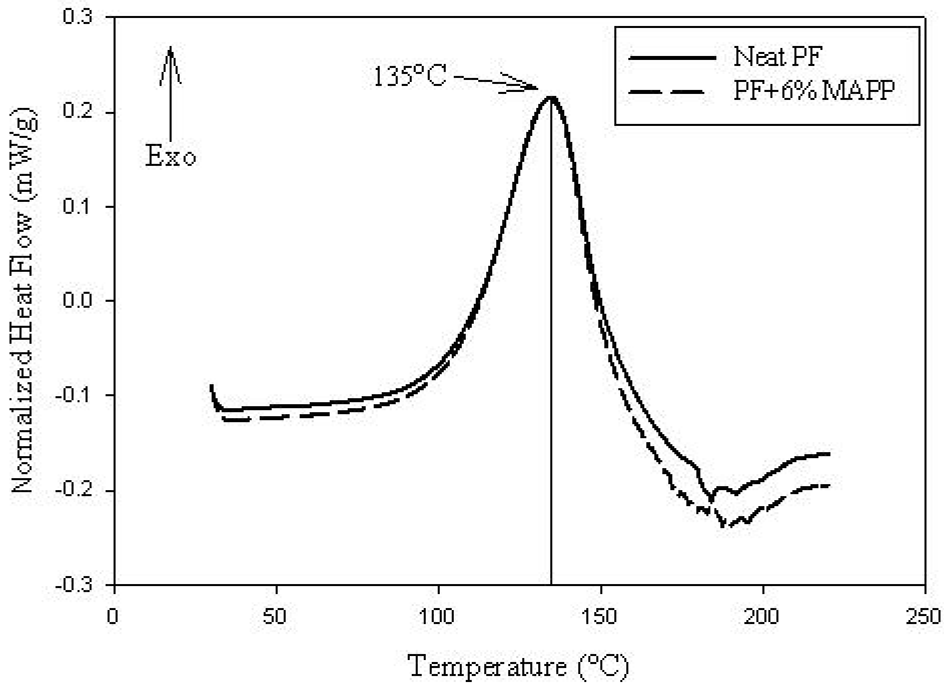

Figure 9. Dynamic ramping of neat PF and PF+ 6% MAPP mixture in DSC.

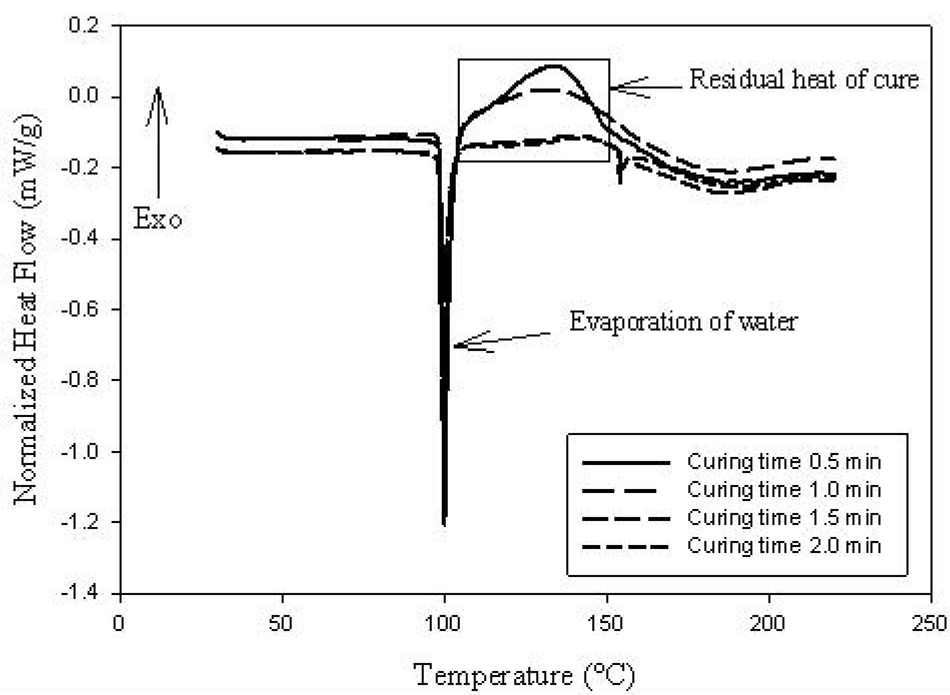

Figure 10. Dynamic temp ramp with cured PF+ 6% MAPP formulations for varying time periods in DSC.

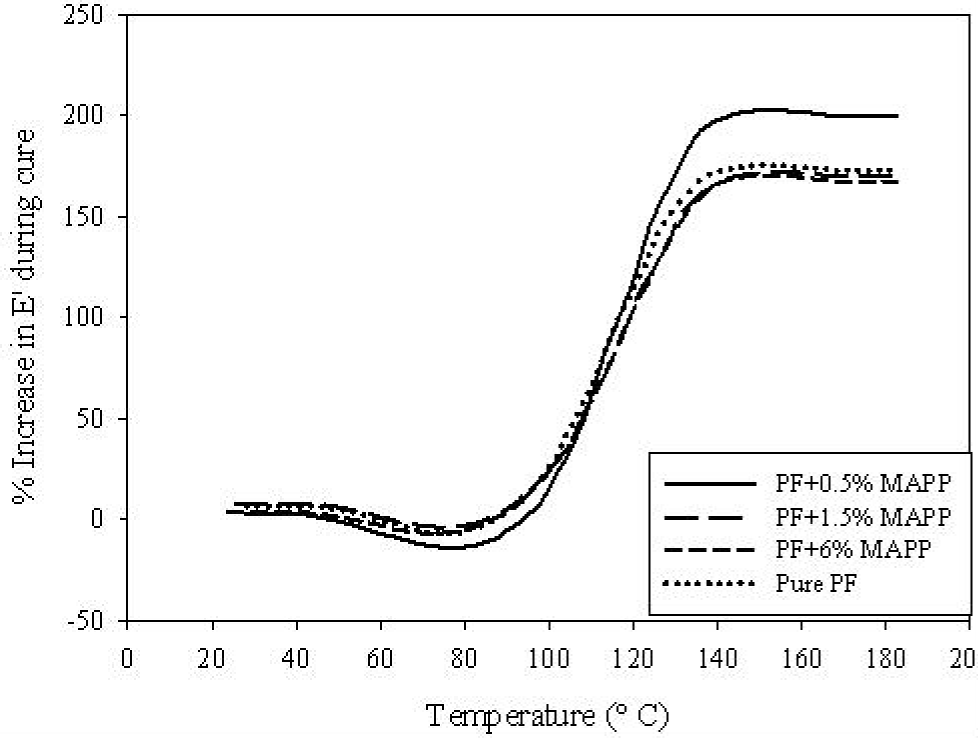

Figure 11. Percentage increase in storage modulus (E′) during curing process with DMA.

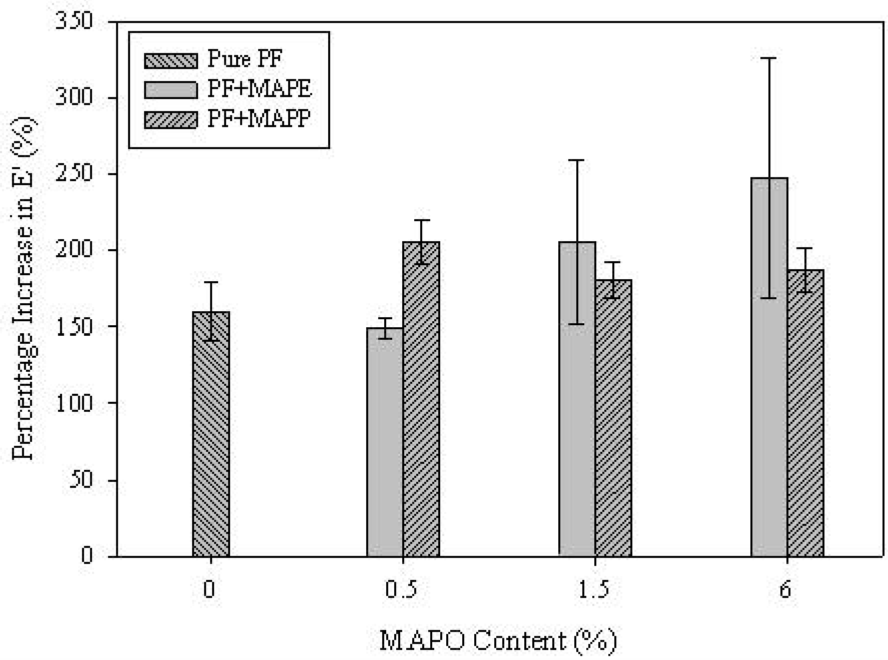

Figure 12. Average percentage increase in storage modulus (E') obtained using DMA for different adhesive formulations.

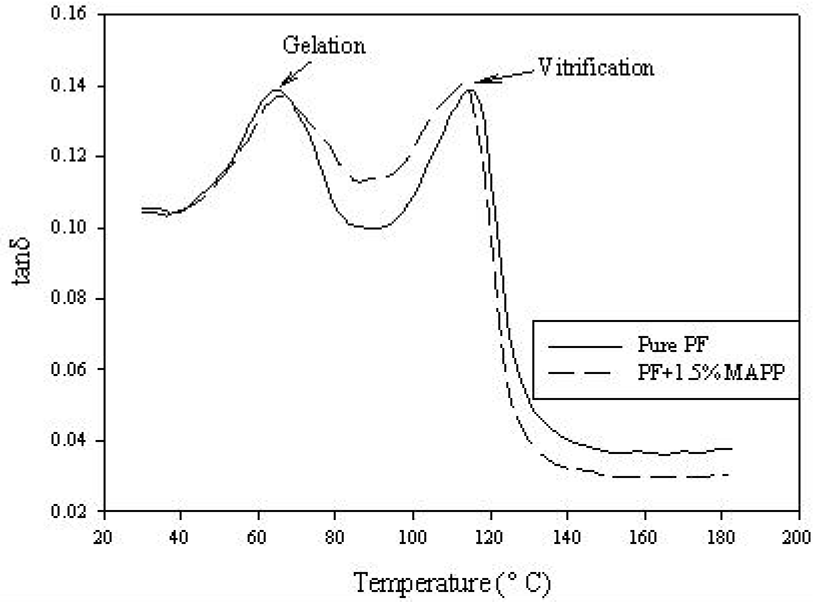

Figure 13. Typical trend of tanδ for adhesive formulations during curing process.

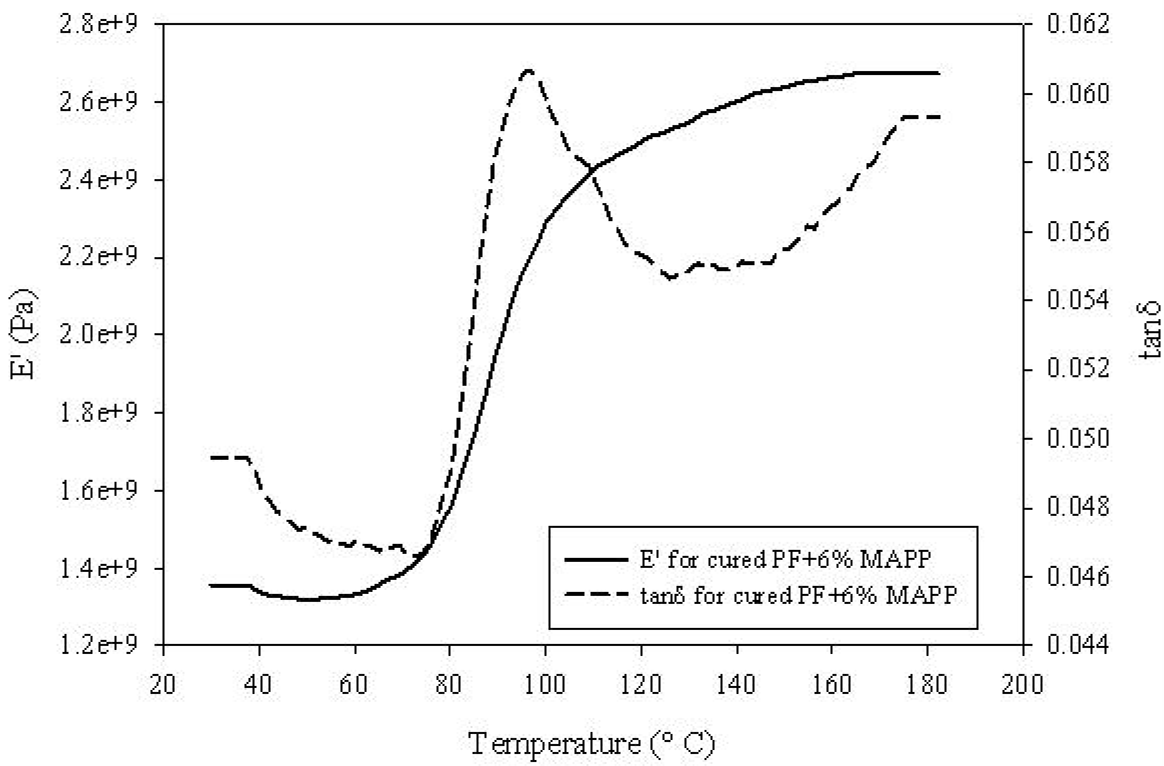

Figure 14. Typical trend of E' and tanδ for the cured laminates under ramping. The increase in the E' is due to loss of moisture.

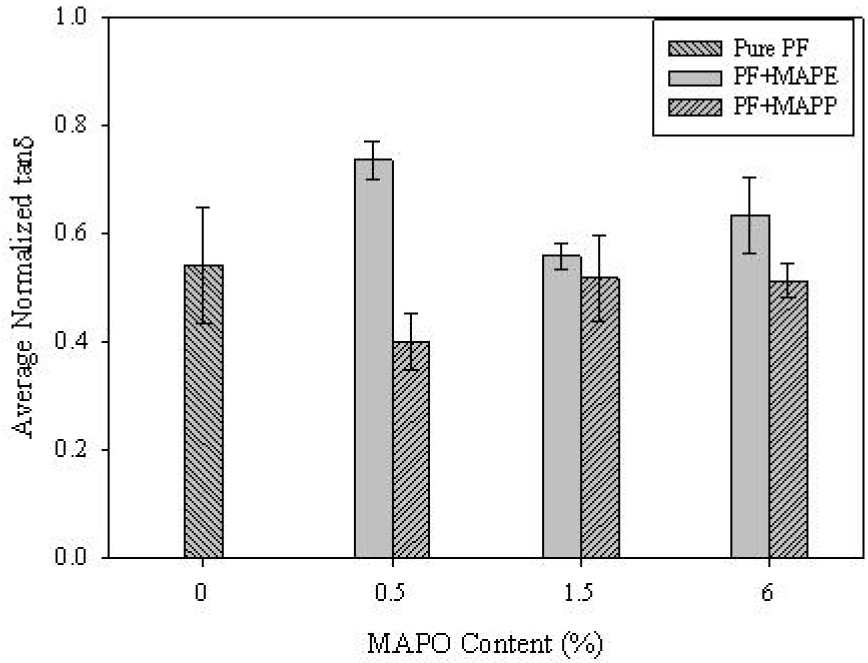

Figure 15. Comparison of normalized tanδ for cured formulations with different proportions of MAPO (MAPE /MAPP) at 40 °C.

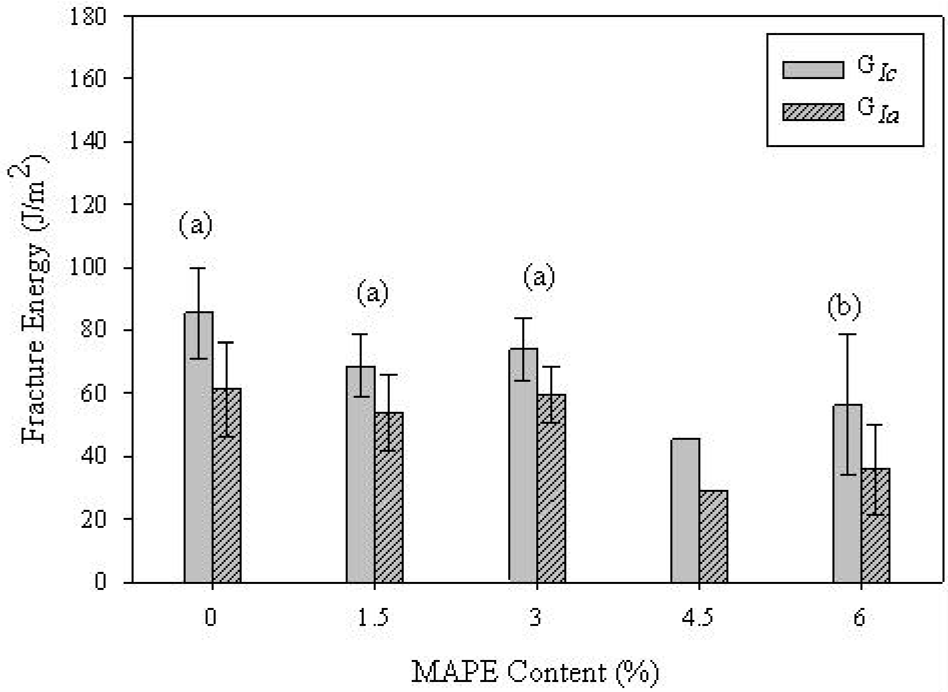

Figure 16. Fracture energies for PF+MAPE formulations at 12% MC; bars with same letters indicate that fracture energies of these blends were not statistically significant from each other at significance level of 0.05.

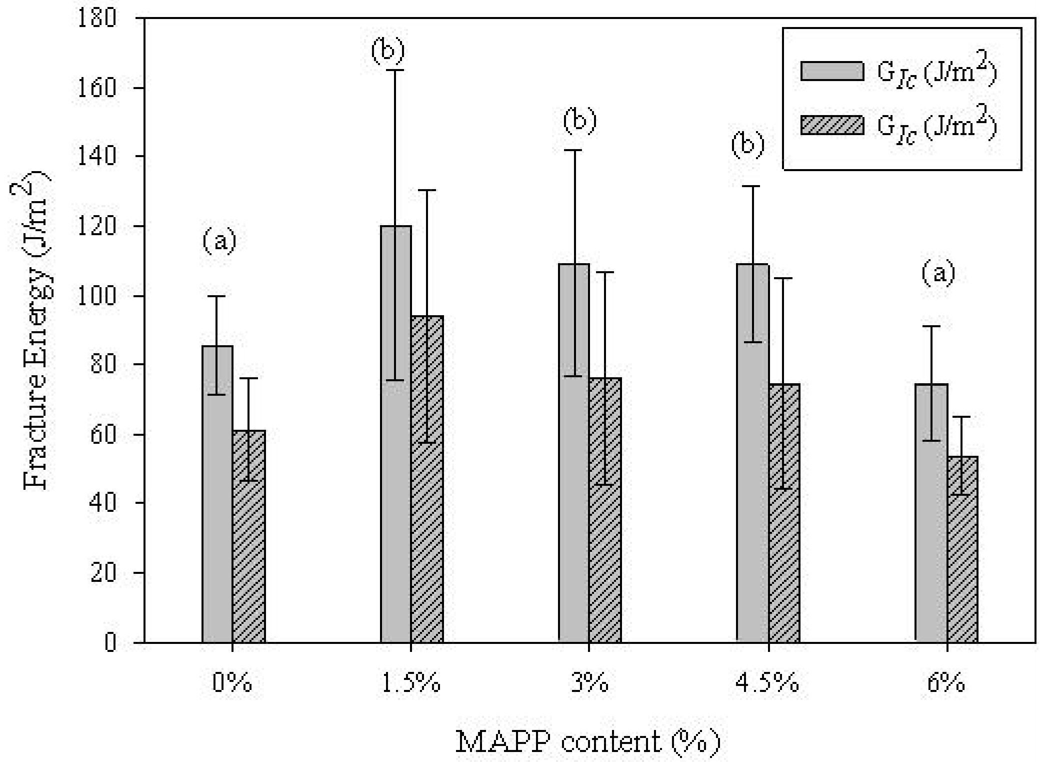

Figure 17. Fracture energies for PF+MAPP formulations at 12% MC; bars with same letters indicate no significant differences in energy values.

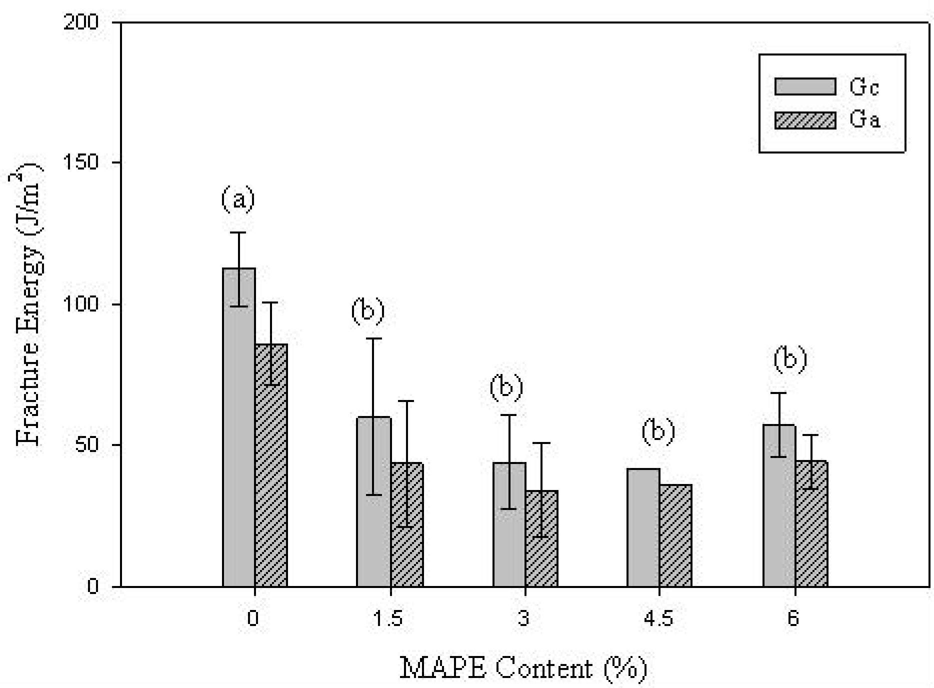

Figure 18. Average fracture energies for formulation with MAPE emulsion after 24-hr water soak. Comparisons of means test results are included on the top of the bars.

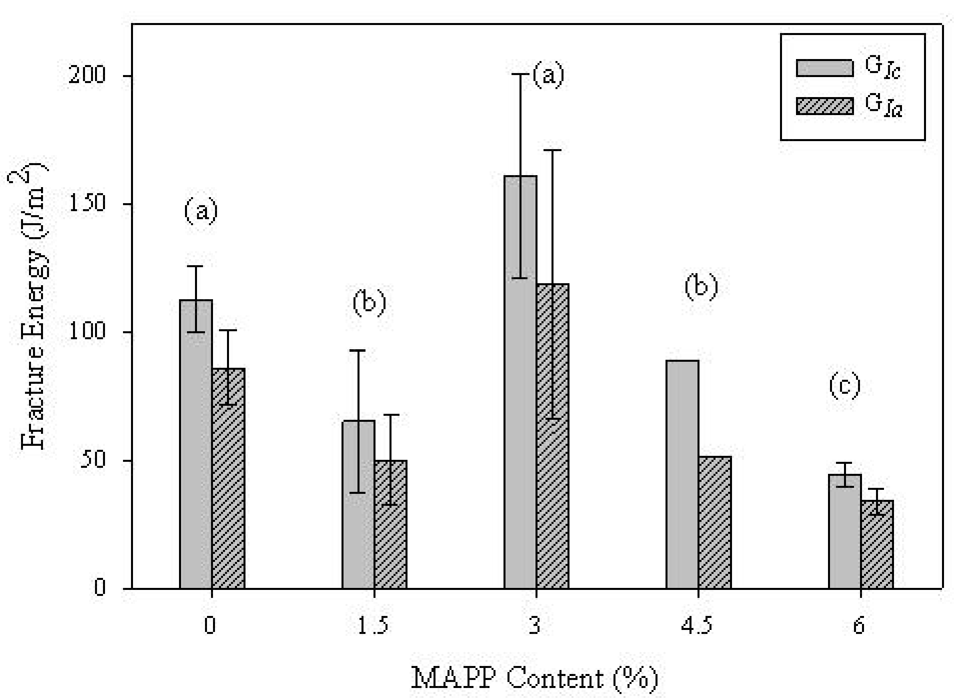

Figure 19. Average fracture energies for formulation with MAPP emulsion after 24-hr water soak. Comparisons of means test results at significance level of 0.05 are included on top of the bars; formulations with same letters indicate no significant difference.

Durable Wood Composites for Naval Low-Rise Buildings

Effect of Coupling Agent and High Resin Content on Physical and Mechanical Properties of Oriented Strand Composite

Integrated Sill Plate Rim Board Elements

Task C2 -- Mechanisms to improve the durability of Oriented Strand Board (OSB)

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Abstract

Moisture intrusion into composite panels in service leads to eventual wetting and degradation of the panels. In this study, a mechanism to improve moisture durability of oriented strand composite (OSC) panels without significantly compromising their mechanical properties was investigated. OSC test panels were hot pressed with adhesive blends consisting varying proportions of phenol formaldehyde (PF) resin and maleic anhydride polypropylene (MAPP) anionic emulsion. Effect of increased levels of PF resin and addition of varying proportions of MAPP on physical and mechanical properties of OSC panels was investigated. To study the efficacy of increased levels of PF and addition of MAPP on moisture resistance and mechanical properties of panels, internal bond, static bending after conditioning to different environmental conditions, water absorption, thickness swell, material permeance, and equilibrium moisture content (EMC) properties were evaluated. MAPP did not significantly affect panel MOE but reduced MOR for 12% MC and 24-hour soak specimens. However, increase in PF content significantly improved MOE and MOR of specimens subjected to both environments. At higher PF levels, IB values were reduced with the addition of MAPP. Water absorption and thickness swelling were also significantly reduced with the addition of MAPP; increasing PF content also had similar effect on water absorption, but also reduced thickness swelling. However, inclusion of MAPP at higher levels in OSC panels significantly reduced water vapor transmission (WVT) and permeance of the material. EMC at 50% and 80% RH indicated that with increasing MAPP content OSC panels equilibrate at lower moisture content. Results of this study indicate that increasing levels of PF is the most effective method of improving both moisture resistance and the mechanical properties of OSC panels; addition of MAPP improves the moisture resistance of the panels, but significantly reduces the mechanical properties, especially MOR and IB.

Introduction

Oriented strand board (OSB) is one of the most widely used panel products in construction industries with 65% of floor, 56% of wall and 72% of roof sheathing market shares in 2003 (SBA 2003). OSB is a structural panel product made of wood strands with exterior grade adhesives like phenol formaldehyde (PF) or polymeric methylene diphenyldiisocyanate (pMDI). As a sheathing material OSB has many positive qualities such as good mechanical properties and excellent insulating properties to heat, sound and electricity. In service, if the OSB sheathing is allowed to breathe properly and is not exposed to high humidity for extended periods, it will not degrade; however, if OSB panels are exposed to high humidity due to poor workmanship, it could lead to their rapid degradation. Decay of wood composites progresses quickly in the moist environments, therefore, any mechanism that can induce moisture resistance to composite panels would help to protect them in service and reduce their susceptibility to decay.

Many researchers have worked on improving the moisture resistance of solid wood and wood composites by reducing the inherent hygroscopicity of wood. Several methods have been used for this purpose including the chemical modification (Chow et al. 1996, Clemons et al. 1992, Youngquist et al. 1986, Arora et al. 1981) and the use of higher phenolic resin content (Beech et al. 1975, Hiziroglu and Kamden 1995, Haygreen and Gertjejasen 1972). Chemical modification process mainly aims at consuming hygroscopic hydroxyl (-OH) group from wood, thus reducing

the moisture affinity (Marcovich et al. 1998). Though chemical modification was found to be effective in reducing the water absorption and thickness swelling of the composites, they often reduced mechanical properties of the finished composites (Marcovich et al. 1998). Higher resin content was another tried method for improving moisture resistance. This method also found to enhance moisture resistance. However, due to the brittle nature of phenolic resin the finished composite would become more brittle, an undesirable mechanical property for a structural material as sheathing. This provided the motivation for this study which aimed to improve the moisture resistance of oriented strand composite (OSC) without significantly compromising its mechanical properties.

It is hypothesized in this study that addition of higher amount of PF could improve mechanical properties and moisture resistance. It is also hypothesized that the addition of a thermoplastic co-polymer coupling agent, such as maleic anhydride polyolefins (MAPO), to the PF adhesive could potentially act as a moisture barrier within the matrix thus improving the moisture resistance of the finished OSC panels. In this study, we hope to understand the effects of interaction between PF resin and MAPP on OSC mechanical and physical properties. In the first phase of this study (Chapter 2), effects of two different MAPO were evaluated for their influence on the energy dissipation and toughness of PF resin system using analytical techniques and fracture toughness tests. It was determined that maleic anhydride polypropylene (MAPP) had better influence than maleic anhydride polyethylene (MAPE). Therefore, MAPP was chosen in this study to mix with PF resin in manufacturing oriented strand composite panels for evaluating its efficacy on improving panel moisture resistance without compromising their mechanical properties.

Objectives

The goal of this study was to understand the effects of varying proportions of PF and MAPP on mechanical and physical properties of OSC panels, especially their moisture resistance properties. Specific tasks to achieve this overall goal include:

1. Determining the effects of increased levels of PF and varying proportions of MAPP on OSC mechanical properties.
2. Investigating the effect of varying PF and MAPP levels on moisture resistance that is reflected in changes to material permeance, equilibrium moisture content, and flexure properties after 24-hour water soak and accelerated aging.

Literature Review

Moisture susceptibility of wood composites has been one of the main concerns of researchers for many years. Techniques such as thermal (Suschland and Enlow 1968) and chemical (Chow et al. 1996, Youngquist et al. 1986 and Arora et al. 1981, Clemons et al. 1992, Mahlberg et al. 2001) modification have been used to reduce the moisture affinity of wood. In heat treatment, finished wood composites are exposed to 165°C to 210°C in an oven (Carll 1997). Thickness swelling of flake boards was found to decrease with heat treatment and the reason was speculated as the further curing of the resin (Carll 1997). Wood has been treated with organic acid anhydrides such as acetic and maleic to consume the free hydroxyl groups (Chow et al. 1996, Youngquist et al. 1986 and Arora et al. 1981). These researchers found significant improvement in dimensional

stability. Treatment of wood fibers (Clemons et al. 1992) and veneers (Mahlberg et al. 2001) with organic acid anhydrides resulted in better moisture resistance. Mahlberg et al. (2001) also found significant decrease in modulus of rupture with these treatments.

Application of higher levels of thermoset resin also found to improve mechanical and physical properties of wood composites (Maloney 1997, Beech 1975, Hiziroglu and Kamden 1995). Maloney (1997) suggested with the increase of resin content in a composite both mechanical and physical properties improved significantly. Beech (1975) found a consistent improvement in thickness swelling properties in particle and flake boards with higher resin content. Hiziroglu and Kamden (1995) found that increased adhesive content (in the range of 0% to 2%) reduced thickness swell of wet-process hardboard (as evaluated by water soak testing), but not significantly. The effects of higher resin content were found to be more evident in particleboard and flake board than in fiberboard (Carll, 1997).

Sun et al. (1994) studied the effect of higher levels of isocyanate and phenolic resin on the physical and mechanical properties of wood fiber composites. A PF resin level of approximately 20 percent was reported to be most efficient in minimizing water absorption and thickness swelling in wet condition while 30 percent resin content was most efficient to reduce the accelerated aging test thickness swelling. Surprisingly, higher resin content did not have any effect on MOE and MOR in dry condition. In wet condition, however, both MOE and MOR were improved with higher resin content and reached a maximum at 30 percent resin level. Better bonding was observed as both dry and wet IB strengths improved with increase of PF resin and reached a maximum at 30 percent level. Wafer board made of PF resin impregnated wafers showed reduced thickness swelling by 35 to 55 percent (Haygreen and Gertjejasen 1972).

Maleic anhydride polypropylene (MAPP) is widely used in wood-plastic composites to enhance compatibility between wood and thermoplastic polymer matrix, consequently improving the mechanical properties of the composite (Felix and Gatenholm 1991, Maldas and Kokta 1991, Stark 1999, Simonsen et al. 1998, Lu et al. 2002). Several researchers investigated the effect of MAPP on the moisture resistance and mechanical properties of wood plastic composites (Marcovich et al. 1998, Patil et al. 2000, Felix et al. 1991). Improvement in dimensional stability was observed when wood was treated with MAPP. Maldas and Kokta (1989) and Snijder et al. (1997) observed that mechanical properties improved with increase of MAPP content up to a certain level beyond which properties either leveled off or decreased. Garcia et al. (2005) treated MDF fibers with MAPP wax and found significant improvement in moisture resistance and mechanical properties of the produced fiber boards. The binders used here were urea formaldehyde (UF) and melamine-urea-formaldehyde (MUF). Use of 3 to 5% MAPP wax resulted in a reduction of 2-hour thickness swelling of the UF boards by 46 to 41%. Decrease in water absorption and linear expansion after 2 and 24 hours of water soaking was also observed. It was also reported that treatment of fibers with MAPP wax improved bending properties and internal bond strength. Wolcott (2003) prepared flat pressed wood panels with wood particles and high density polyethylene (HDPE). It was found that use of HDPE, water absorption and thickness swelling decreased: whereas, mechanical properties were adversely affected with the increasing proportion of thermoplastic. More recently, Zheng et al. (2004) studied the rheological behavior, penetration characteristics, and fracture performance of liquid phenol-formaldehyde resole and polymeric diphenylmethane diisocyanate (pMDI) hybrid mixtures.

They observed that hybrid properties are a function of simple emulsion effects. Improvement in toughness of PF matrix was significant at low pMDI levels due to dispersed urethane/urea/biuret phase; however, dispersed-PF phase resulting from addition of small quantities of PF to urethane/urea/biuret matrix did not result in a significant improvement of resin toughness.

The premise of this study is that use of thermoplastic co-polymer coupling agent will impart moisture resistance to OSC through creating a barrier to moisture movement while not compromising the mechanical properties of the composite significantly. Another hypothesis is that use of higher amount of PF will improve the properties of panel. This study should also investigate how the interaction of PF and MAPP influence mechanical properties of OSC. Previous phase of this study (Chapter 2) indicated that the addition of MAPP emulsion improved the fracture toughness of PF blend. Higher toughness of adhesive can improve moisture resistance of composites by lowering the crack propagation within a panel, thus allowing fewer pathways for moisture to infiltrate.

Measurement of equilibrium moisture content, diffusion constant and permeance have been used by many researchers as a tool of measuring the moisture resistance of wood and wood composites (Wu and Suchsland 1996, Clemons et al. 1992, Marcovich et al. 1999, Hukka 1999, Hartley and Schneider 1993, Wu and Lee 2002, Rangaraj and Smith 2000). They have found these methods of testing to be useful in understanding the moisture resistance of wood and wood composites.

Materials and Methods

Materials

Commercially available wood strands consisting of 60% aspen and 40% mixed hardwoods were obtained from Weyerhaeuser and used for fabricating oriented strand composites in the laboratory. Average nominal dimensions of strands were 71 mm by 13 mm by1 mm. Typical OSB grade phenol formaldehyde resin (57% solid content) from Dynea Chemical was used. Maleic anhydride polypropylene (MAPP) anionic emulsion from Honeywell Chemicals was used as results of the first phase of the overall study (Chapter 2) revealed that maleic anhydride polypropylene (MAPP) anionic emulsion had performed better than maleic anhydride polyethylene (MAPE) anionic emulsion in improving toughness and moisture resistance of PF resin system. The emulsion had a solid content of 30%. Polymethylene diphenyl diisocyanate (pMDI) panels were prepared to serve as control specimens. pMDI bonded panels are accepted in the industry to yield board that have improved moisture resistance properties and better mechanical properties. pMDI adhesive was obtained from Bayer (Monodur® 541).

Experimental Design

Experimental design was established based on D-optimal response surface design using a design of experiment software (Design-Expert®, Stat-Ease 2006). PF resin and MAPP emulsion were considered as factors affecting the response variables (such as flexure properties, internal bond, percent water absorption, etc.). Both PF and MAPP were calculated on the basis of dry weight of wood. The low and high levels for these factors of were as follows: PF content ranged from 6

to 25% and MAPP content varied from 0 to 6%. The D-optimal design, which minimizes the error of the model coefficients, suggested that 20 runs were necessary. Better representation of design space was obtained by adding 6 more runs. Therefore a total of 26 runs were performed to evaluate the effect of variables. Experimental design points or runs, indicating the proportions of PF and MAPP for different runs, as suggested by response surface design are tabulated in Table 1.

Table 1. Formulations and number of panel replicates suggested by D-optimal resonse surface design.

MAPP Content (%)	PF Content (%)	Number of Replicates
0	6	2
0	12	1
0	25	2
0.5	18	2
1.5	10	1
1.5	22	1
2	6	2
3	6	1
3	15.5	2
3	25	2
4	6	1
4	10	1
4.5	20	1
6	6	2
6	15	2
6	25	3

Oriented Strand Composite (OSC) Fabrication

Wood strands were dried to 3% moisture content in a rotary drum drier. Dried strands were then screened with a 38 mm (1.5 inch) square screen to separate fines. Amount of strand, PF and MAPP emulsion required for OSC preparation were calculated to obtain a final board density of 640 kg/m^3 (40 lb/ft^3). It should be noted that amount of PF and MAPP were calculated based on dry weight of wood. Dimensions of the hot-pressed panels were 860 mm by 860 mm by 15.9 mm (34 inches by 34 inches by 0.625 inches). After fabrication the edges of the panels were trimmed (76.2 mm from each side) to get constant density. Therefore, the final dimensions of the test panels were 711.2 mm by 711.2 mm by 1.59 cm (30 inches by 30 inches by 0.625 inches).

Blending

Strands were then blended with PF resin and MAPP emulsion in a rotary blender. Initially, PF and MAPP emulsion were mixed thoroughly in a liquid blender and the mixture was sprayed. This method ensured proper distribution of MAPP into PF before spraying. However, spraying this mixture proved to be difficult as the mixing process generated lot of foam which clogged the spraying nozzles and slowed down the blending process significantly. Therefore, an alternate

process was adopted where PF resin and MAPP emulsion were sprayed simultaneously from two sets of nozzles. This method was found to be convenient resulting in a uniform distribution of PF and MAPP emulsion throughout the spraying process without clogging up the nozzles. To ensure a good blend and even distribution of resin and emulsion, MAPP was added in small batches as the resin was being blended (this was especially critical at higher resin levels as emulsion, due to smaller quantities, would otherwise be atomized completely before resin). It was assumed that PF and MAPP blend together as they are deposited on strands in an atomized form and would behave similar to being mixed together prior to atomizing. This method was preferred over the earlier one because of its ease of application.

Blended strands (furnish) were then hand formed in a forming box of size 860 by 860 mm (34 by 34 inches). The forming box had metal vanes spaced 76.2 mm (3 inches) apart for proper alignment of the strands. After forming, the mats were pressed in a hot press to form an oriented strand composite.

Hot-Pressing

Pressing temperature and time were determined based on the studies done on cure kinetics of resin blends (Chapter 2). It was found through DSC study that 2.5 minutes at 145°C temperature resulted in approximately 98% cure of adhesive blends. Test runs were performed with temperature and gas probe to determine the pressing schedule which ensured that the core of the mat reached 145°C and stayed at that temperature for at least three minutes. Single layer, unidirectional strand mats were hot pressed at 182°C (360°F) using required amounts of resin and emulsion to a target density of 640 kg/m^3 (40 lb/ft^3). A 30-minute pressing schedule included 8 minutes of close time, 20 minutes hold and 2 minutes of vent time (1minute after 10 minute of holding and 1 minute at the end of holding time). Pressed panels were then trimmed to final dimension. Three OSC panels were hot-pressed with 3% pMDI resin. Similar platen temperature (182°C) was maintained as for PF panels. Pressing time was reduced as the required curing temperature for pMDI resin was 100°C. A 24 minutes pressing cycle included 8 minute of close time, 15 minutes hold time and 1 minute vent time at the end.

Testing of OSC Panels

Specimens for mechanical and physical testing of finished panels were cut as shown in Figure 1. Flexure, internal bond, and water absorption and thickness swell tests were performed according to ASTM D1037 (ASTM 1999a). Water vapor transmission and permeance were determined following the guidelines outlined in ASTM E96 (ASTM 1994). Equilibrium moisture content was also determined for test panels as a measure of moisture affinity. Diffusion constants for specimens were calculated to examine moisture diffusion property of panels with different formulations.

Evaluation of Mechanical Properties

Flexure Properties

Static bending test specimens were divided into three groups and each group was subjected to different environmental conditions prior to testing. From each panel six flexure specimens were obtained. Two specimens were randomly assigned to each of the environmental conditions. A set of specimens were placed in a controlled environment chamber with 20°C temperature and 68% relative humidity for two weeks to equilibrate to 12% MC. Second set of specimens were soaked in water for 24 hrs and were tested immediately after that. The third set of specimens was subjected to accelerated aging cycles as instructed in ASTM D1037. Six cycles were performed after which the specimens were placed in 12% equilibrium moisture content room for 48 hrs before testing for their flexure properties. Specimens were 431 mm in length by 76 mm in width by 15.9 mm in depth (17 by 3 by 0.625 inches). Speed of the testing was calculated on the basis of specimen dimension according to the formula suggested by the ASTM D1037; it was determined to be 7.62 mm per minute (0.3 inches/min).

Internal Bond Test (IB)

Standard internal bond tests were performed after conditioning the samples at 12% moisture content. Six specimens were obtained from each board. Dimension for the internal bond test specimens were 50.8 mm square (2″ by 2″) by the thickness of the panel. Standard procedure mentioned in ASTM D1037 was followed for sample preparation and calculating the testing speed (1.27 mm per minute (0.05 inch/min)). Maximum load at failure was recorded from which stress at failure was calculated using specimen cross section dimensions.

Evaluation of Physical Properties

Water Absorption and Thickness Swelling Test

Water absorption and thickness swelling tests were performed for short term soaking (2 hrs) and long term soaking (24 hrs). Specimens of dimensions 152.4 mm by 152.4 mm (6″ by 6″) by thickness of the panel were soaked in water following standard procedure. Two specimens for each run were tested. Water absorption was calculated as a percentage from initial weight and final weight. Similarly, thickness swelling also was calculated as a percent change from the initial thickness.

Permeance Measurement

Moisture resistance of test panels was investigated by measuring water vapor transmission (WVT) and permeance according to ASTM E 96 (ASTM 1994). Water vapor permeance can be defined as the time rate of water vapor transmission through unit area of flat material or construction induced by unit vapor pressure difference between two specific surfaces, under specified temperature and humidity conditions (ASTM 1994). Desiccant method was chosen for this test (Figure 2).

One specimen from each board was tested. Specimens of dimensions 152.4 mm by 152.4 mm (6 inches by 6 inches) were first wax coated on the edges and then placed over the open mouth of a plastic container of dimensions 146 mm square (5.75 inch square) by 63.5 mm (2.5 inch) in depth. Before placing the specimens, the containers were partially filled with 350 g of

anhydrous calcium chloride ($CaCl_2$). Anhydrous calcium chloride is a desiccant and would act as moisture sink. $CaCl_2$ absorbs moisture from the surrounding causing 0% relative humidity in the air between specimen and itself resulting in a moisture gradient between the two sides of the specimen. This would be the driving force for the moisture to flow through the OSC specimen. Specimens were sealed on the edges of plastic container using a silicone gel sealant. The whole system was placed in a controlled environment of 50% relative humidity and 22°C temperature. They were then weighed periodically to determine the moisture gain. Initially measurements were recorded every 6 hours and after steady state was reached, weights were recorded once a day. A straight line was fitted to the linear region of the plot. The slope of the steady state per unit area represents the rate of water vapor transmission (ASTM 1994). From that value permeance was calculated according to ASTM E96 (1994).

EMC and Diffusion Constant Measurement

Equilibrium moisture content of the panels was determined by subjecting specimens of dimensions 101.6 mm by 101.6 mm (4 inches by 4 inches) by the thickness of the panel to two different environmental conditions: 80% relative humidity at 30°C temperature and 50% relative humidity at 22°C temperature. Procedures followed by previous researchers were used as guidelines for this test (Wu and Suchsland 1995, Lee and Biblis 1976). In the first step specimens were dried in an oven at 100°C until constant weights were reached. Specimens were then put into the test chambers at specified temperature and relative humidity as stated above. Weight gains of the specimens were measured periodically. Final moisture gain and the rate of moisture gain of test panels with different adhesive formulations were graphically compared from the percent moisture gain vs. time plot. In the next step, moisture weight gain is plotted against the square root of time for all specimens subjected to both environmental conditions. Evidence of a linear initial region of moisture-related weight gain indicates that water movement into material followed Fick's law of diffusion at initial stage (Rangaraj and Smith 2000, Pierron et al. 2002, Chateauminois et al. 1994). The percent weight gain, M, initially varies linearly with the square root of time, t, according to Fick's law (Rangaraj and Smith 2000).

$$M = \frac{4M_m\sqrt{D_A}}{h\sqrt{\pi}}\sqrt{t} \qquad \text{Equation 1}$$

Where,
M_m = Percent weight gain at saturation (%)
D_A = Apparent diffusion constant (mm^2/s)
t = Time (s)
h = Thickness of the specimen

Apparent diffusion coefficient (D_A) was determined from slope of the linear region of the moisture gain vs. square root of time plot as,

$$D_A = \pi\frac{h^2}{16M_m^2}\left[\frac{M_2 - M_1}{\sqrt{t_2} - \sqrt{t_1}}\right]^2 \qquad \text{Equation 2}$$

Here, M_2 and M_1 are percent moisture gain at corresponding time t_2 and t_1. This apparent diffusion constant is calculated for one dimensional moisture flow, i.e., through thickness of the

specimens. Correction for moisture flow through the edges are done by calculating the geometric edge correction factor, ECF (Rangaraj and Smith 2000) as,

$$ECF = \left(1 + \frac{h}{L} + \frac{h}{w}\right)^2 \qquad \text{Equation 3}$$

In this equation L, w and h are length (mm), width (mm) and thickness (mm) respectively.

Now the corrected diffusion constant (D) was calculated using Equation 4 as,

$$D = \frac{D_A}{ECF} \qquad \text{Equation 4}$$

Diffusion constant values were then compared and statistically analyzed to evaluate the effect of different formulations on moisture diffusion through the test specimens.

Results and Discussion

Experimental results were analyzed using Design-Expert® version 7software (Stat-Ease Inc. 2006). Results obtained from tests were fed into the response surface model discussed earlier and analyzed to examine the effects of PF and MAPP levels on the properties (response variables) of the test panels. It has been well established that properties of composite panels is directly correlated with their density. Therefore, statistical analyses were conducted taking specimen density as a covariate where significant. SAS (SAS Version 9, 2002) was used to perform covariance analysis considering PF and MAPP levels as independent variables and density as a covariate. If density effects were significant, significance of PF and MAPP levels was evaluated for each test after adjusting for the density factor.

Mechanical Properties

Flexure Properties at 12% Moisture Content

Response surface for MOE as the two independent variables, MAPP and PF levels, are varied within their low and high values is shown in Figure 3. Analysis of variance (ANOVA) indicated that level of MAPP content did not have a significant effect on MOE at 0.05-alpha level (Model R^2=0.6). However, PF content and density of the specimens had a significant effect on MOE. Analysis of covariance (ANCOVA) was then performed to adjust MOE values for density to examine the effects of PF and MAPP levels without the interference of density factor. Analysis indicated that PF effect was still significant only for 3% MAPP content level (p-value = 0.0056), whereas for other MAPP content levels there was no significant effect of PF content (p-value range 0.3497 to 0.7592). MAPP effect was not significant (p-value = 0.8085) considering density as a covariate. This finding was contrary to what was reported by Mahlberg et al. (2001) where they found an increase of 20% in MOE when fiber boards were treated with maleic anhydride. This difference could be explained due to the presence of thermoplastic (polypropylene) in addition to maleic anhydride in this study. As the response surface indicates,

however, MAPP had a positive influence on specimen MOE at lower levels of PF (<15%) and a negative effect above this level. Influence of PF on MOE values of panels with 6% MAPP and varying PF contents are plotted in Figure 4. It is evident from the plot that with an increase in PF content the MOE increase significantly; an increase of 19% in MOE with an increase of PF content from 6% to 25%.

Results also indicate that panels with PF and MAPP blends performed significantly better than the pMDI panels. Specimens with 6% PF and MAPP each were found to have 20% higher MOE than pMDI panels. Specimens with 6% MAPP and 25% PF had 44% more average MOE than pMDI specimens. Whereas, panels made with 6% neat PF had 10% more average MOE than pMDI specimens. Comparison of means at 0.05 significance level indicated that specimens with 6% PF content were significantly different than 15% and 25% PF content specimens, whereas, 15% and 25% PF content panels were not found to be significantly different.

Effect of varying levels of MAPP and PF on MOR of test panels is presented in Figure 5. The model indicates that MOR significantly increases with increasing PF content, whereas significantly decreases with increasing levels of MAPP (Model R^2= 0.4). Analysis of variance indicated that density effects where significant (p-value = 0.0009). Thus, model was adjusted by taking density as a covariate. ANCOVA indicated that did not have significant effect on MOR of panels (p-value rage = 0.0699 to 0.5726). Analysis also showed MAPP content had significant effect on MOR (p-value = 0.0187) especially at lower PF level (6%), whereas at higher PF level this effect was not significant (p-value = 0.1869).

Trend of MOR of OSC specimens at varying MAPP content at 6% and 25% PF levels are shown in Figure 6. These values were also compared with MOR of panels bonded with pMDI resin. Decrease in MOR as MAPP content was increased from 0 to 6% remained constant at all levels of PF resin (approximately 20%). Similar trend was also noticed by Mahlberg et al. (2001), where a 20% drop in MOR value was reported when fiber boards were treated with maleic anhydride. Average MOR value for pMDI boards was less than neat PF boards and was comparable with boards bonded with PF and 6% MAPP. This trend also held true with increasing levels of resin content.

Static Bending Test after 24- hr Water Soak

Static bending tests were performed after soaking the specimens in water for 24-hour.MOE and MOR values for specimens after 24 hours water soak were compared with MOE and MOR of 12% MC specimens. Proportion of MOE and MOR retained after 24 hours water soak were calculated by dividing MOE/MOR values of 24-hour water soak specimens by MOE/MOR values obtained from 12% MC specimen from the same test panel. Obtained values were then statistically analyzed as before.

Analysis of variance showed that MAPP content had a significant effect on retention of MOE values after 24 hours water soak of the specimens (p-value = 0.0048) whereas, PF content (p-value = 0.4322) and density (p-value = 0.0516) did not have significant effect on MOE retention. Figure 7 shows the response surface of proportion of MOE retained with the variation of PF and MAPP levels (Model R^2 = 0.3).

It was observed that with the increase in the MAPP content the proportion of MOE retention decreased. For panels with 6 and 25% PF content when MAPP levels were varied from 0 to 6% decrease in retention of MOE were observed (~25% for 6% PF content and 11% for 25% PF content panels). Figure 8 shows the comparison of fraction of MOE retention for 6 and 25% PF content panels at varying MAPP levels. When compared with fraction of MOE retained by pMDI panels it was found that pMDI panels had lower retention of MOE than panels with neat PF (34% lower than 25% PF panels and 23% lower than 6% PF panels). Though bar graphs (Figure 8) shows there is an increase in retention of MOE with increase in PF content, the response surface model did not show any significant effect of PF content on MOE retention.

The response surface for fraction of MOR retained after 24 hour water soak is shown in Figure 9. The model (Model $R^2 = 0.4$) suggested that MAPP content (p-value = 0.0001) and density had significant effect on fraction retention of MOR of the specimens (p-value = 0.0169). However, PF content (p-value = 0.5258) did not have a significant effect.

Analysis of covariance was performed with density as a covariate. Results suggested MAPP content at lower PF level (6%) significantly reduced MOR retention (p-value = 0.0270). Whereas, at higher PF levels this effect was not significant (p-value = 0.3726). Fraction of MOR retained was decreased with the increase in MAPP content in the panels. However with the increase in density the MOR retention was increased. MOR retention was compared for 6 and 25% PF content panels at varying MAPP levels (Figure 10). It was found that for 6% PF content specimens with the increase in MAPP content the fraction of MOR retention decreased. Increase in MAPP content from 0 to 6% resulted in a drop in MOR retention by 45%. For 25% PF content panels increase in MAPP from 0 to 3% initially enhanced the MOR retention by nearly 20% but further increase in MAPP content did not have much effect.

Static bending test after accelerated aging cycles

Flexure properties of the specimens were tested after subjecting them to accelerated aging cycles. Six cycles of accelerated aging (ASTM 1999a) were found to be too severe for the OSC test specimens. Sixty two percent of the specimens fell apart after the completion of 2 cycles; and, fifty percent of pMDI bonded specimens fell apart or failed after 2 cycles. It was observed that specimens with higher amount of PF resin content performed better under these severe conditions. This trend was also observed by previous researchers, where higher resin content (30%) panels performed better under accelerated aging (Sun et al. 1994). Table 2 and 3 summarizes fraction of MOE/MOR retained after accelerated aging.

Table 2. List of fraction of MOE retained after accelerated aging of static bending specimens. Values in the parenthesis represent COV.

MAPP \ PF	6	10	12	15	15.5	18	20	22	25	pMDI
0	**Failed**		**0.793**	*	*	*	*	*	**0.764 (23%)**	**0.338 (12%)**
0.5	*	*	*	*	*	**0.882 (36%)**	*	*	*	
1.5	*	**0.266**	*	*	*	*	*	**0.489**	*	
2	**Failed**	*	*	*	*	*	*	*	*	
3	**Failed**	*	*	*	**0.132**	*	*	*	**0.247 (20%)**	
4	**Failed**	**Failed**	*	*	*	*	*	*	*	
4.5	*	*	*	*	*	*	**Failed**	*	*	
6	**Failed**	*	*	**Failed**	*	*	*	*	**0.194**	

* Blend with this composition was not tested

Table 3. List of fraction of MOR retained after accelerated aging of static bending specimens. Values in the parenthesis represent COV.

MAPP \ PF	6	10	12	15	15.5	18	20	22	25	pMDI
0	**Failed**		**0.676**	*	*	*	*	*	**0.635 (45%)**	**0.338 (12%)**
0.5	*	*	*	*	*	**0.935 (36%)**	*	*	*	
1.5	*	**0.289**	*	*	*	*	*	**0.410**	*	
2	**Failed**	*	*	*	*	*	*	*	*	
3	**Failed**	*	*	*	**0.207**	*	*	*	**0.264 (19%)**	
4	**Failed**	**Failed**	*	*	*	*	*	*	*	
4.5	*	*	*	*	*	*	**Failed**	*	*	
6	**Failed**	*	*	**Failed**	*	*	*	*	**0.203**	

* Blend with this composition was not tested

Internal Bond Test

Internal bond (IB) tests were performed after conditioning the samples at 12% moisture content. This test reflects the tensile strength of the test panel perpendicular to the surface and is an indirect measure of fastener holding properties. Stress at failure was calculated for each specimen. Analysis of data using D-optimal response surface model yielded a response surface for IB values as MAPP content and PF content varied (Figure 11).

The analyzed model, with an R-square of 0.5, suggests that all three factors, namely PF content (p-value = <0.0001), MAPP content (p-value = <0.0001) and density (p-value = <0.0001), had significant effect on internal bond strength. As MAPP content increased, the internal bond strength significantly decreased; however, PF content and density had positive effect on IB strengths as expected. Analysis of covariance with density as a covariate further indicated that increasing PF content had significant effect on increasing IB (p-value range = 0.0057 to 0.0351); however, at higher MAPP levels (higher than 3%) increasing PF did not show significant effects (p-value range = 0.0550 to 0.7285). Analysis also suggested that MAPP levels reduced IB strength significantly (p-value range = 0.0005 to 0.0044). Figure 12 compares IB values for specimens at 6% and 25% PF levels for different MAPP levels.

For 25% PF content panels a decrease of 56% in IB strength was observed as MAPP content was increased from 0% to 6%. Comparison of means test at 0.05 significance level showed that 3% and 6% MAPP content specimens were significantly lower than specimens without MAPP. Figure 13 compares IB at 6% MAPP content with varying PF levels. As the PF content was increased from 6% to 25%, a 34% increase in IB strength was observed at MAPP level of 3%.

On the basis of static bending and IB test results it could be seen that higher amount of PF resin significantly improve the mechanical properties. This finding supports the hypothesis that higher PF content improved mechanical properties. However addition of MAPP reduced mechanical properties especially at higher levels. This was against our study hypothesis that addition of MAPP would improve panel's mechanical properties. It was however observed that addition of lower amount of MAPP did not severely affect the properties.

Evaluation of Physical Properties

Water Absorption and Thickness Swelling

Effect of MAPP and PF contents on moisture properties after short term (2hour) and long term (24-hour) water soak tests were evaluated as per ASTM D 1037 (ASTM 1999a). Response surface analyses were performed on water absorption and thickness swelling results using Design-Expert® software.

Short term (2 hours) water absorption and thickness swelling

Water absorption after 2 hours was calculated as a percentage of initial weight. Response surface model ($R^2 = 0.84$) suggested that varying MAPP and PF contents had significant impact (p-values less than 0.0003) on 2-hour water absorption values, whereas density effects were not significant. Increase in MAPP and PF contents decreased water absorption of test specimens (Figure 14). Effect of increasing MAPP content at 6% and 25% PF levels after 2-hr water absorption test is shown in Figure 15. An average drop of over 28% in water absorption was observed at both 6% and 25% PF levels as MAPP content was increased from 0% to 6%.

Response surface for thickness swelling after 2-hour water soak is shown in Figure 16 (model $R^2 = 0.92$). Analysis showed that PF factor was significant (p-value < 0.0001), whereas MAPP did not influence thickness swelling significantly. Figure 17 presents changes in thickness swelling

after 2-hr water soak for two different PF contents (6% and 25%) at varying MAPP levels. As PF content was increased from 6% to 25%, at 3% MAPP level, a 65% decrease in thickness swelling was observed. Increase in MAPP content showed a significant change in thickness swelling only at higher PF level (a decrease of 27%).

Long term (24- hour) water absorption and thickness swelling

Figure 18 shows response surface (model $R^2 = 0.83$) for long term water absorption (24 hours) with varying MAPP content and PF contents. Analysis of variance indicated that both MAPP and PF content had significant effects on long term water absorption (p-values < 0.0049). Once again, density effects were not significant. Figure 19 compares long term water absorption results for 6% and 25% PF contents at varying MAPP levels.

There is a sharp decrease in water absorption as PF content was increased from 6 to 25% percent (a reduction of 38% at 3% MAPP level). MAPP content also decreased water absorption values, but not so significantly. At 6% PF level, increase in MAPP content from 0% to 6% decreased water absorption by 12%; whereas, at 25% PF content, the water absorption reduced by 29%. Panels manufactured with higher PF content (25%) performed better than pMDI panels after 24-hour soak tests.

Changes in long term thickness swelling as MAPP and PF contents were varied are shown in Figure 20. Response model (model $R^2 = 0.92$) suggests that both MAPP and PF effects were significant for long term thickness swelling (p-value < 0.0001). Increase in PF content decreased thickness swell, similar to water absorption tests; but, contrary to waster absorption results thickness swell increased as MAPP content was increased, especially at lower PF levels. This may be justified by the fact that longer soaking time allowed water to diffuse into the cell wall causing increase in the thickness swelling. Figure 21 shows a comparison of thickness swelling for 6% and 25% PF content panels at varying MAPP levels.

At 25% PF level, increase in MAPP content did not have much impact on thickness swelling. PF content though had a considerable effect on thickness swelling as MAPP level was kept constant. Figure 22 compares the effect of varying PF content at 6% MAPP level on thickness swelling. A 63% decrease in thickness swelling was observed as the PF content was increased from 6% to 25%. Higher PF content panels were also found to have better resistance to thickness swelling than pMDI panels. Thickness swell could have increased with increasing MAPP level at lower PF content as a result of cell walls absorbing more water. However, due to bulking of cell lumens and between-strand voids with MAPP, water absorption did not necessarily increase with increasing MAPP levels, but instead decreased.

Water absorption and thickness swelling values for test panels were found to be much higher than commonly expected in commercially produced oriented strand composites, such as OSB. These values were also found to be higher than what was observed by other researchers (Gu et al.2005). It is believed that a reason for this is the quality of furnish used in this study. It was observed that there are wide variations in strand dimensions used in producing test panels. Dai and Steiner (1997) suggested that flake dimensions have great impact on the horizontal density of finished panels; as length, width and thickness change, the variance in panel density increases.

This effect is reflected in specimen density variations within each of the groups. Distributions of strand dimensions where characterized to confirm this hypothesis. Dimensions of 150 randomly chosen strands were measured and distributions were plotted (Figure 23). As distributions indicate, thickness and width of the strands used in this study had wide variations.

Between width and thickness, the later has a more pronounced effect on density variation of the test panels (Dai and Steiner 1997). Variation in horizontal density results in higher between-strand void volume. Voids in the panel results in more absorption of water as found by Wolcott (2003). Therefore, in this study, it is speculated that wide variations in strand dimensions resulted in values of water absorption and thickness swelling values.

Water Vapor Transmission (WVT) and Permeance

Water vapor transmission and permeance were measured according to guidelines specified in ASTM E 96 (ASTM 1994) to evaluate the effect of varying amounts of MAPP and PF on moisture resistance characteristics of OSC panels. Typical examples of moisture gain vs. time plots are shown in Figure 24.

From the slope of the moisture gain vs. elapsed time graph, rate of water vapor transmission (WVT) for each specimen was calculated, and using WVT values, permeance for each specimen was calculated. These permeance values were then fed into the previously used D-optimal response surface model to see the effects of PF and MAPP content on the permeance of the oriented strand composite. Figure 25 shows the response surface for permeance as the MAPP content and PF content were varied.

The response surface model ($R^2 = 0.83$) suggested that both MAPP and PF content had significant effect on permeance of the specimens (p-values < 0.0006). Density of test specimens was also observed to have a significant effect (p-value = 0.0011). An analysis of covariance (ANCOVA) was performed taking density as a covariate. Results indicated that MAPP effect was still significant (p-value = 0.0010) as for permeance; however, in the adjusted model PF was found to have no significant effect (p-value = 0.3624) on the permeance property of the specimens. Thus, results indicate that MAPP does play a significant role in reducing the permeance of the panels supporting the hypothesis that it aids in improving the moisture resistance.

It could be seen from the response surface plot of permeance (Figure 25) that with an increase in MAPP content permeance of the specimens decreased significantly especially at lower levels of PF. Change in permeance with varying MAPP content is plotted in Figure 26 for two extreme levels of PF. For 6% PF content panels, increment in MAPP content from 0% to 6% resulted in a decrease of permeance of test panels by 23%. The permeance of 6% PF panel with 3% MAPP content was 37% lower than that of pMDI panels.

Comparison of EMC and Diffusion Constant

Equilibrium moisture content of test panels was evaluated after subjecting the specimens to two different environmental conditions. First set of specimens were subjected to 50% relative

humidity (RH) and 22°C and the second set of specimens were subjected to 80% RH and 30°C. Moisture weight gain was plotted as a function of time for all formulations and examined to compare equilibrium moisture contents and relative rates of moisture sorption. Diffusion constants of test panels were compared to investigate differences in relative rates of moisture sorption as a result of varying proportions of PF and MAPP.

Specimens subjected to 50% RH and 22°C

Initially, when oven dried specimens where placed in the test chamber, they absorbed moisture rapidly and over time gradually equilibrated as expected. Figure 27 compares the trend in moisture weight gain for 6% PF content panels with varying MAPP content. The values were graphically compared with moisture weight gain of pMDI test specimens. As MAPP content was increased from 0% to 6%, the equilibrium moisture content of panels decreased from 7.39% to 6.99%. Panels bonded with pMDI resin equilibrated to higher moisture content when compared with 6% PF content panels with varying MAPP levels. Similar trend was also observed for higher PF content panels; at 25% PF level, EMC decreased from 7.08% to 5.79% as MAPP content was increased from 0 to 6%. Figure 28 shows the moisture weight gain as a function of time for panels with 25% PF and varying MAPP content. Increase in PF content while holding MAPP level constant did not significantly reduce rate of moisture uptake and EMC (Figure 29). With increase of PF content from 6 to 25% at 3% MAPP content the equilibrium moisture content decreased from 6.99%% to 6.41%.

Diffusion constant for test specimens were calculated. Typical plot for moisture gain vs. square root of time is shown in Figure 30. Plots showed that the specimens initially gain moisture linearly and then gradually starts to equilibrate. Fick's law of diffusion was applied at the linear region to determine the diffusion constants for each specimen using Equations 1 to 4. Table 4 summarizes diffusion coefficient values for different formulations.

Figure 31 compares diffusion constant of 6% and 25% PF content panels at different MAPP levels. pMDI panels were found to have higher diffusion constant values than panels made with PF. Diffusion constants of 6% and 25% PF panels were lower than that of pMDI panels by 25% and 37% respectively. For 25% PF content panels with the increase of MAPP content from 0 to 6% resulted in a decrease of diffusion constant by 20%.

Table 4. List of diffusion constant for specimens subjected to 50% RH.

MAPP \ PF	6	10	12	15	15.5	18	20	22	25	pMDI
0	**8.50E-05**		**6.07E-05**	*	*	*	*	*	**7.16E-05**	**1.14E-04**
0.5	*	*	*	*	*	**4.99E-05**	*	*	*	
1.5	*	**6.78E-05**	*	*	*	*	*	**5.10E-05**	*	
2	**6.48E-05**	*	*	*	*	*	*	*	*	
3	**8.79E-05**	*	*	*	**7.66E-05**	*	*	*	**6.41E-05**	
4	**7.39E-05**	**6.53E-05**	*	*	*	*	*	*	*	
4.5	*	*	*	*	*	*	**5.58E-05**	*	*	
6	**7.79E-05**	*	*	**5.31E-05**	*	*	*	*	**5.69E-05**	

* Blend with this composition was not tested

Specimens subjected to 80% RH and 30°C

Figure 32 compares the trend of moisture weight gain over time for 6% PF test panels with varying MAPP content and for pMDI bonded test panels. Rate of moisture weight gain was significantly different for panels with higher MAPP content. At 6% PF content, with increase in MAPP level from 0 to 6%, EMC of test panels decreased from 10% to 8%. Results also indicate slower rates of moisture gain with increasing levels of MAPP. Panels with 0% MAPP content had similar trend of moisture gain as that of pMDI panels, whereas with the increase in MAPP content the rates of moisture gain were lowered and the panels equilibrated at lower moisture content.

Moisture weight gain over time for panels with 3% MAPP and varying PF contents is shown in Figure 33. The effect of increasing PF content is not as significant as in the case of varying MAPP content, especially at higher PF levels. With an increase of PF content from 6% to 25%, a decrease in equilibrium moisture content of 5% was observed. When compared with pMDI panels, all the formulations were found to have lower EMC than pMDI panels.

Diffusion constants for specimens at 80% RH are given in Table 5. Typical plots of moisture gain vs. square root of time are shown in Figure 34. It was found that specimens initially gained moisture linearly and then gradually starts to equilibrate. This trend was typical for materials that follow Fickian behavior. Fick's law of diffusion was applied at that linear region to determine the diffusion constant.

Table 5. List of diffusion constant for specimens subjected at 80% RH.

MAPP \ PF	6	10	12	15	15.5	18	20	22	25	pMDI
0	1.52E-04		1.04E-04	*	*	*	*	*	1.00E-04	1.43E-04
0.5	*	*	*	*	*	1.22E-04	*	*	*	
1.5	*	1.13E-04	*	*	*	*	*	9.72E-05	*	
2	1.38E-04	*	*	*	*	*	*	*	*	
3	1.61E-04	*	*	*	1.06E-04	*	*	*	1.04E-04	
4	1.25E-04	1.21E-04	*	*	*	*	*	*	*	
4.5	*	*	*	*	*	*	1.01E-04	*	*	
6	1.20E-04	*	*	1.03E-04	*	*	*	*	9.59E-05	

* Blend with this composition was not tested

Figure 35 compares the diffusion constants for 6 and 25% PF content panels at varying MAPP levels. pMDI panels showed higher diffusion constant than specimens bonded with 25% PF. However 6% PF content panels had comparable diffusion constants as that of pMDI panels. For 6% PF content panels with the increase in MAPP content from 0 to 6% resulted in a decrease in diffusion constant by 21%.

Results indicate that MAPP content had a prominent effect on lowering the EMC of OSC panels besides lowering the rate of moisture gain over time. Diffusion constant was also decreased with the addition of MAPP and higher PF content also showed similar effect. Infiltration of moisture takes place through the voids and micro pores (Wong et al 1999). Addition of thermoplastic MAPP could cause in bulking these pores. This could result in lowering the diffusion constants of the OSC.

Results of tests conducted to evaluate the physical properties were found to follow the hypotheses made at the start of this study. It was hypothesized that addition of MAPP and higher PF content would increase moisture resistance of the panels. Permeance and diffusion constant values showed that addition of MAPP had significant influence in increasing moisture resistance of the panels.

To evaluate the efficacy of varying levels of PF and proportion of MAPP on properties of OSC panels, measured mechanical and physical properties for different resin blends were compared using radar plots. For every formulation property values were ranked. An index was generated for each value where maximum preferred value for each property (i.e., highest values for mechanical properties and lowest values for physical properties) had value of 1 and least preferred value had a value of 0. These indices were then plotted in the form of a radar plot.

Figure 36 represents the comparison of properties at 6% PF content with increasing MAPP levels. The plot indicates that addition of MAPP reduced permeance and water absorption properties of the test panels. However addition of MAPP found to increase thickness swelling. Addition of MAPP also showed detrimental effects on mechanical properties, especially MOR and IB.

Effects of varying levels of PF at a constant MAPP level (6%) were monitored in Figure 37. The plot indicates that higher PF content panels (25% PF) performed best both in terms of mechanical and physical properties. Increasing PF content is found to have more significant effect on MOE and MOR retentions after 24 hour water soak, water absorption and thickness swelling, permeance and diffusion constant. Increasing PF content from 6 to 15.5% improved 12% MOE, MOR and internal bond (IB) values, but further addition seemed to have no effect on these properties due to the inclusion of MAPP.

Figure 38 compares the properties of two different PF content panels (6 and 25%) with and without 6% MAPP. The plot indicates that 25% PF content panels performed best in terms of improving mechanical properties. At 25% PF content, addition of 6% MAPP reduced mechanical properties and performed similar to neat 6% PF content panels. Thickness swelling was also increased with the addition of MAPP. However, addition of MAPP seemed to improve moisture resistance properties by reducing permeance, diffusion constant and water absorption. Panels showed lowest permeance, diffusion constant and water absorption for panels with 25% PF and 6% MAPP.

Conclusions

This study was undertaken to investigate a proof of concept that higher levels of PF resin with inclusion of thermoplastic copolymer coupling agent in producing oriented strand composite will improve its moisture resistance properties without compromising its mechanical properties significantly. Following are some general conclusions of this study:

- Use of higher PF levels was most effective in improving both physical and mechanical properties of OSC panels.

- MAPP level in OSC test panels has a significant influence on their water vapor transmission and permeance. At 6% PF content, increase in MAPP content from 0 to 6% resulted in a reduction of permeance by 23%.

- Equilibrium moisture content (EMC) measurement at 50% and 80% RH conditions indicated that with increasing MAPP content OSC panels equilibrate at lower moisture content. Additionally, increasing MAPP reduces the rate of moisture gain. Specimens found to follow Fick's law of diffusion. Diffusion constants were found to reduce with the addition of MAPP. Panels bonded with PF and MAPP formulations were found to have lower diffusion constants than pMDI panels.

- Results indicated that MAPP content reduced water absorption in long term and short term water soaking tests. For 6% PF content panels, the increase of MAPP content

from 0 to 6% resulted in a drop of 28% and 12% respectively in short term and long term water absorption. Increasing PF content also significantly reduced water absorption in both short and long term water soak tests. At 3% MAPP level, the increase in PF content from 6 to 25% resulted in a decrease in water absorption by 49% in short term soaking and 38% in long term soaking.

- Two hour water soak thickness swelling reduced with the addition of MAPP; however, contrary was true for 24-hour water soak tests. PF content reduced thickness swelling for both short and long term water soak tests. For short and long term soaking cases, a considerable reduction in thickness swelling (over 60%) was observed as PF content was increased from 6 to 25% percent at 3% MAPP level.

- Static bending test for specimens at 12% moisture content indicated that MAPP content had a two fold affect on panel MOE; higher MAPP content at lower levels of PF improved MOE, but at higher levels of PF (over 15%), the trend reversed. OSC test panels showed a significant improvement in MOE with increasing levels of PF resin. For specimens after 24 hours water soak addition of MAPP had adverse effect on MOE. Fraction of MOE retained was reduced with the increase in MAPP content.

- MOR of specimens at 12% moisture content was significantly reduced as MAPP content of the test panels was increased. A drop of 19% in MOR was observed as MAPP content was increased from 0 to 6% at a constant PF level. Increasing PF content had significant positive impact on MOR. For 24 hour water soak specimens addition of MAPP had different effects for lower and higher PF content panels. At 6% PF level addition of MAPP caused lowering in MOR retention. However, at 25% PF content addition of 3% MAPP showed an improvement in MOR retention by 20% but further increase in MAPP did not show any significant difference.

- Internal bond strength was significantly reduced with the increase in MAPP content, especially at higher PF levels. Increasing PF content considerably improved IB strength of the panels. At 3% MAPP content, the increase of PF content from 6 to 25% resulted in the increase of IB strength by 65%. Large variations in strand geometry used in this study could have also affected internal bond quality of test panels.

From this study, it can be concluded that higher PF content improved mechanical and physical properties of OSC test panels. It was also inferred that addition of thermoplastic co-polymer coupling agent, such as MAPP, at low levels could significantly improve moisture resistance properties of OSC panels; however, addition of MAPP could have detrimental effects on their mechanical properties, especially MOR and IB.

Acknowledgements

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Figures

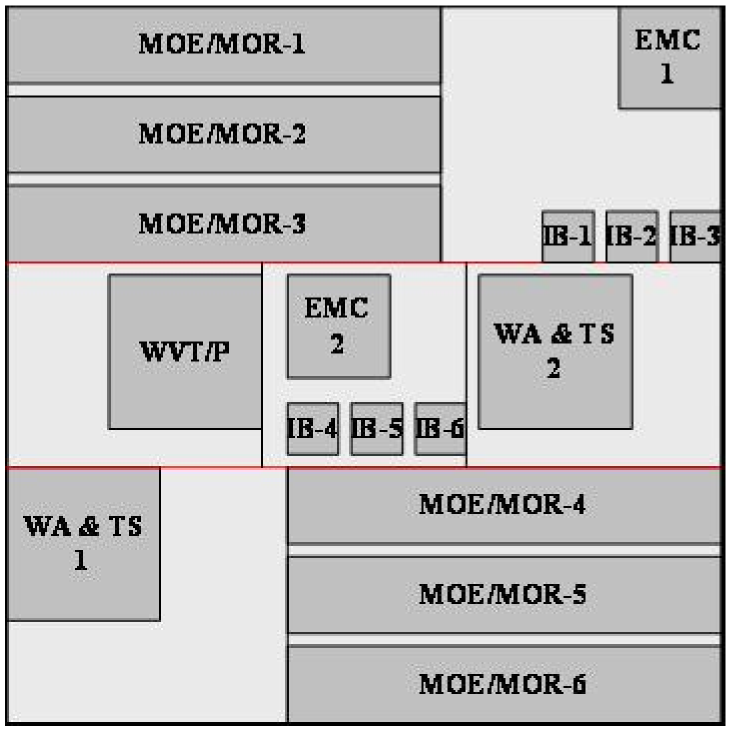

Figure 1. Cutting pattern of test specimens from OSC test panels. Six flexure (MOE/MOR), six internal bond (IB), two water absorption and thickness swelling (WA & TS), two equilibrium moisture content (EMC) and one water vapor transmission and permeance (WVT/P) specimens were prepared from each test panel.

Figure 2. Test setup for water vapor transmission and permeance measurement.

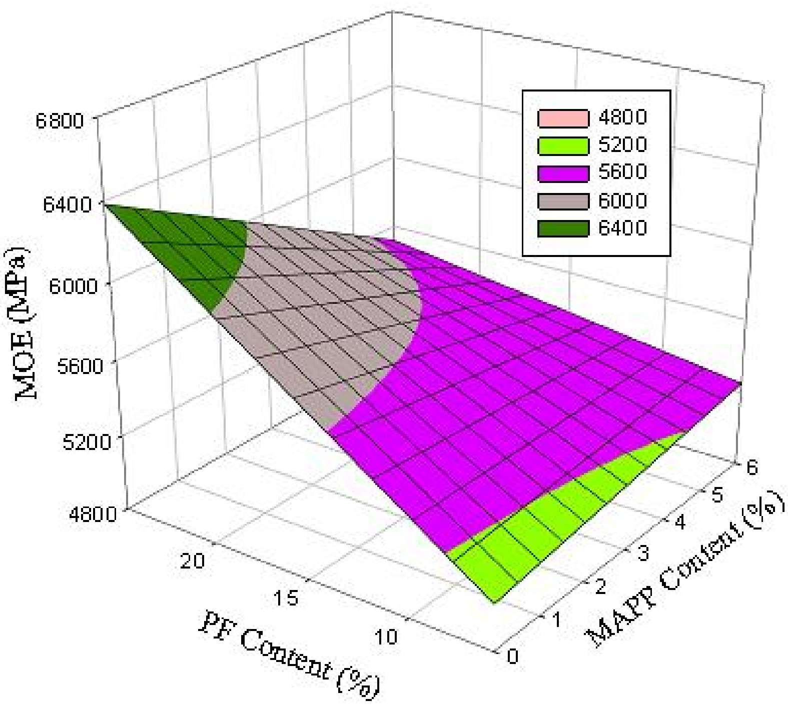

Figure 3. Response surface for MOE with varying MAPP and PF levels for specimens at 12%MC and a fixed target density of 641 kg/m^3.

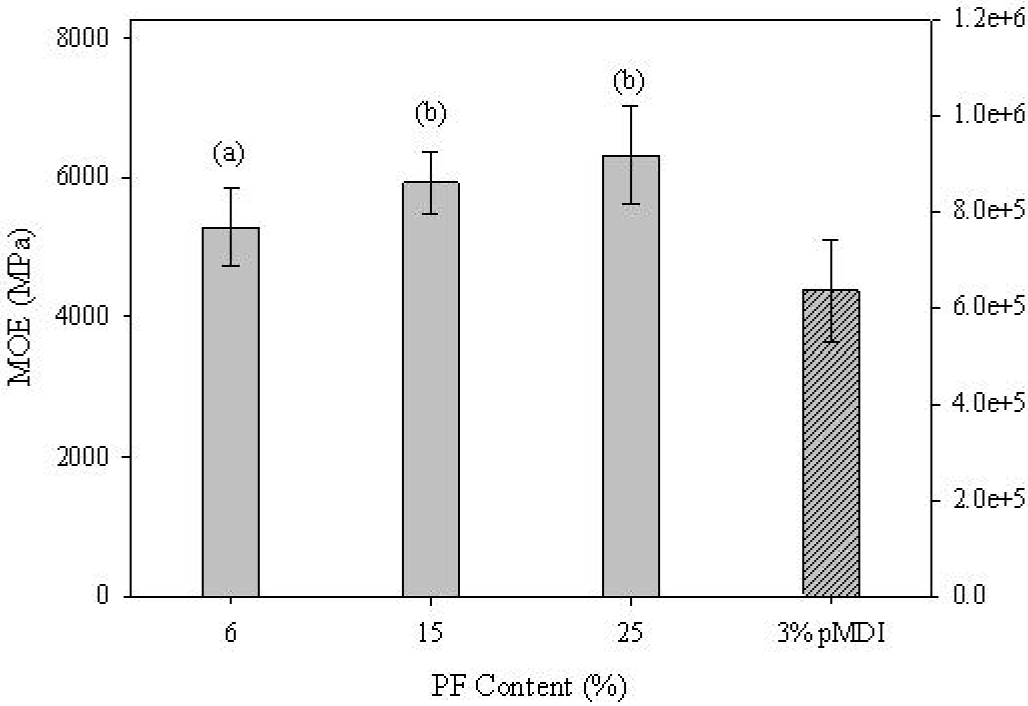

Figure 4. Comparison of MOE of panels with 6% MAPP and varying PF levels and pMDI at 12%MC. Comparison of mean (Duncan) test results at 0.05 significance level are shown on top of the bars.

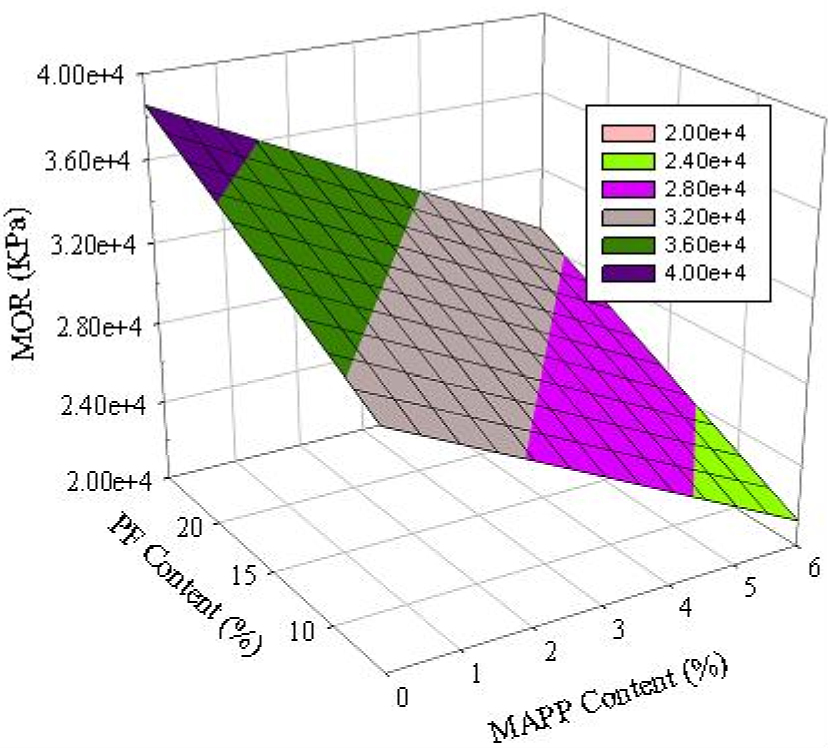

Figure 5. Response surface for MOR with varying levels of PF and MAPP for 12% MC flexure specimens at constant target density of 641 kg/m^3.

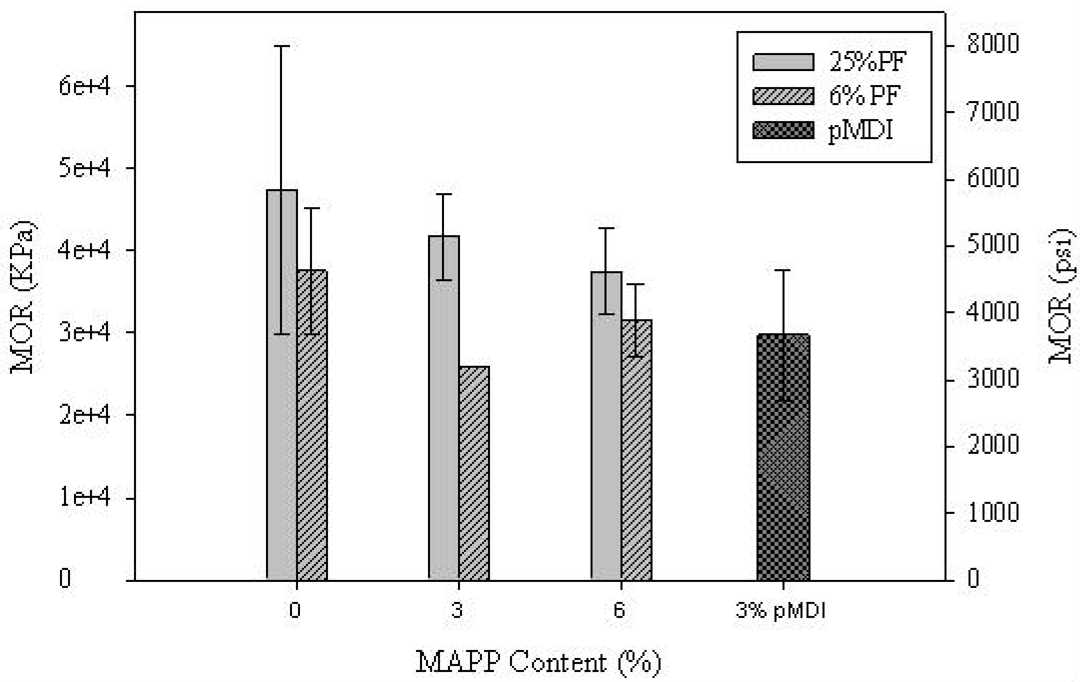

Figure 6. Comparison of MOR for boards with varying MAPP levels at 6% and 25% PF levels and pMDI at 12% MC.

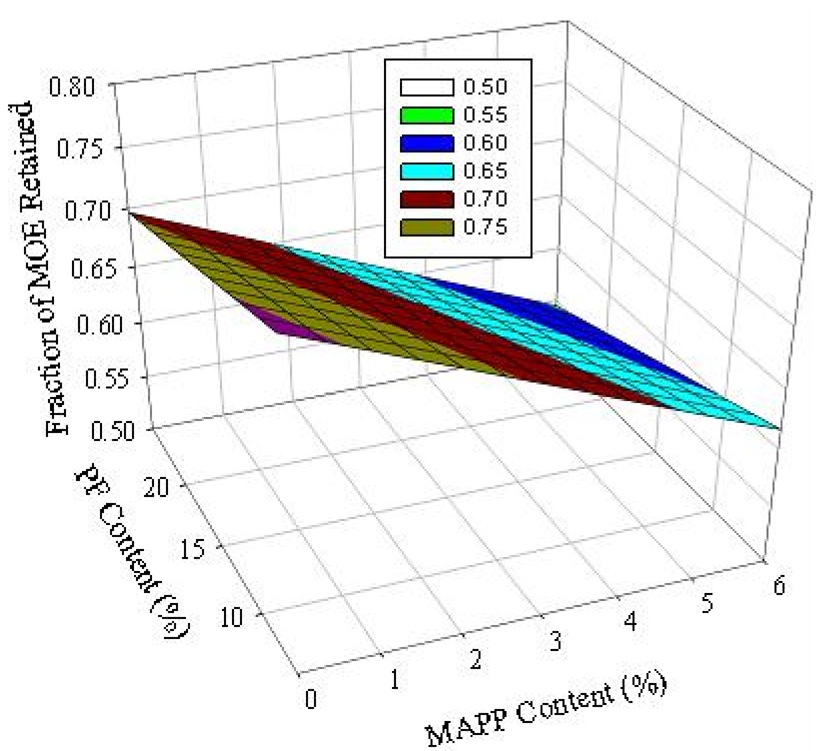

Figure 7. Response surface for fraction of MOE retained after 24 hours water soak of static bending specimens.

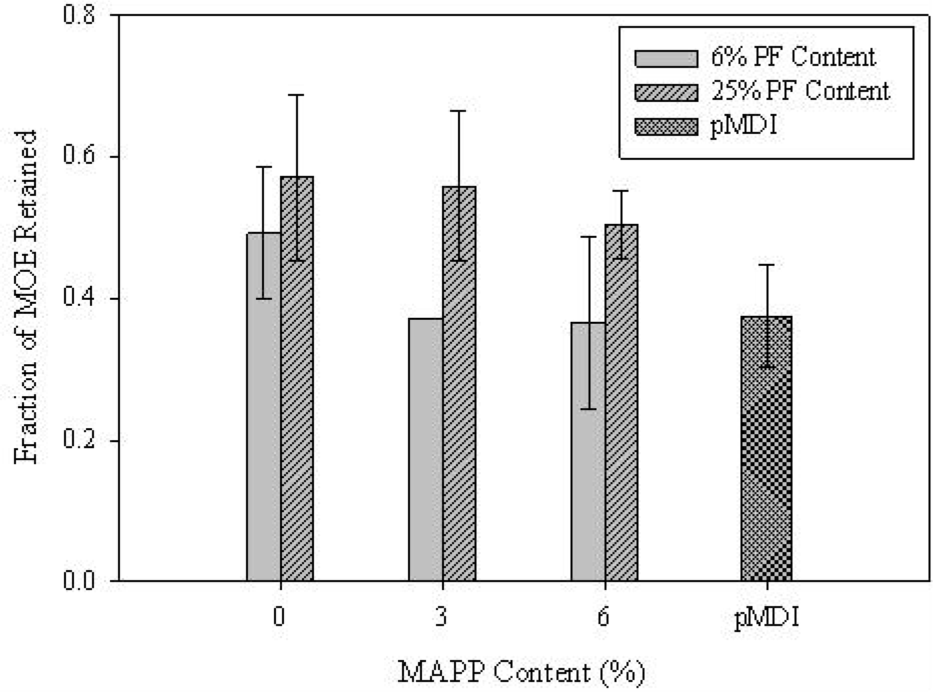

Figure 8. Comparisons of fraction of MOE retained after 24 hour water soak for panels with 6 and 25% PF content at varying MAPP levels. Fraction of MOE retention for pMDI panels is also included.

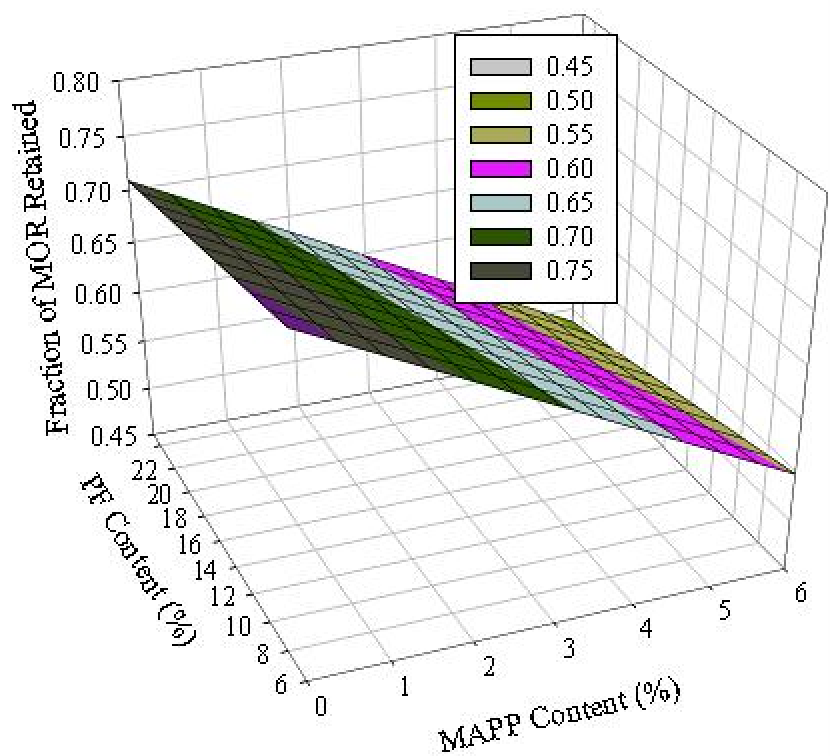

Figure 9. Response surface for fraction of MOR retained with varying levels of PF and MAPP for static bending specimens after 24 hours water soak.

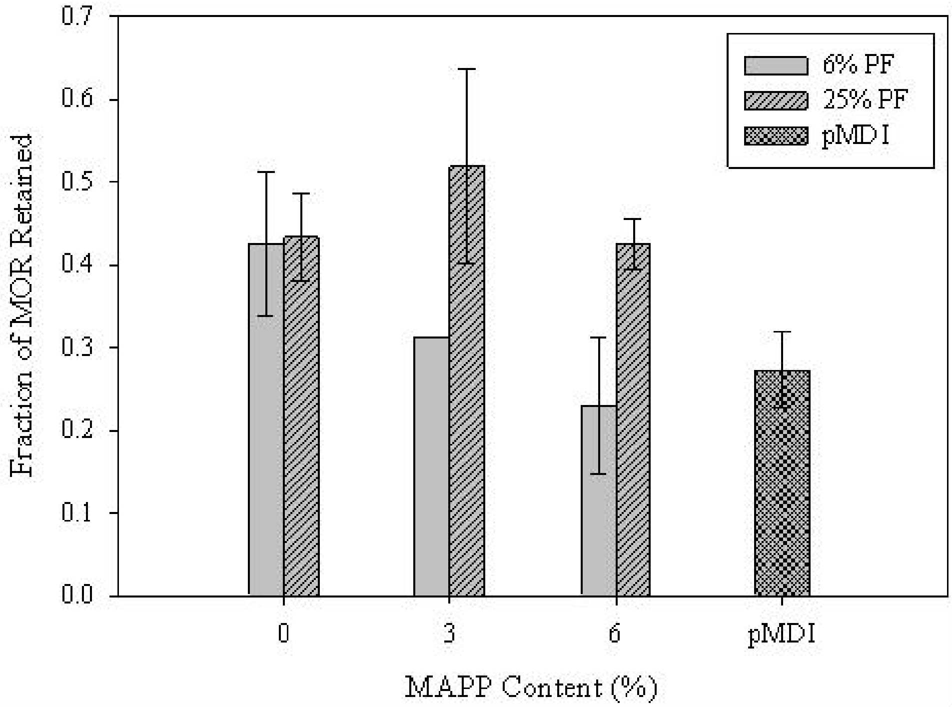

Figure 10. Comparisons of fraction of MOR retained after 24 hour water soak for panels with 6 and 25% PF content at varying MAPP levels. Fraction of MOR retention for pMDI panels is also included.

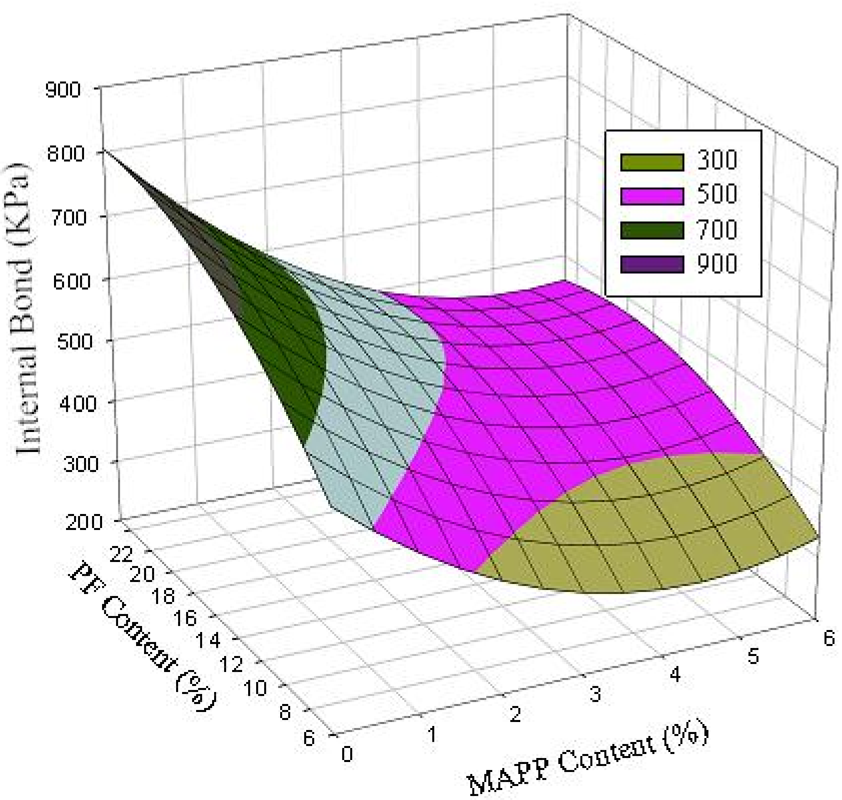

Figure 11. Response surface plot for internal bond strength at varying levels of MAPP and PF.

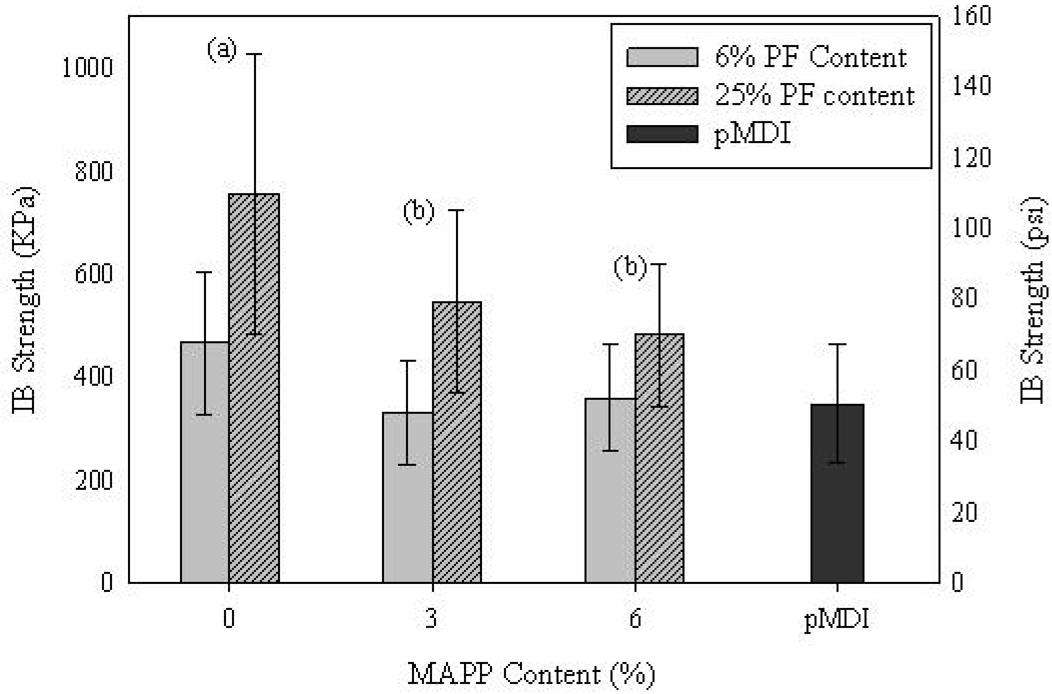

Figure 12. Comparison of internal bond strength for specimens at 6% and 25% PF levels with varying MAPP contents and pMDI resin. Comparison of means test results are also indicated.

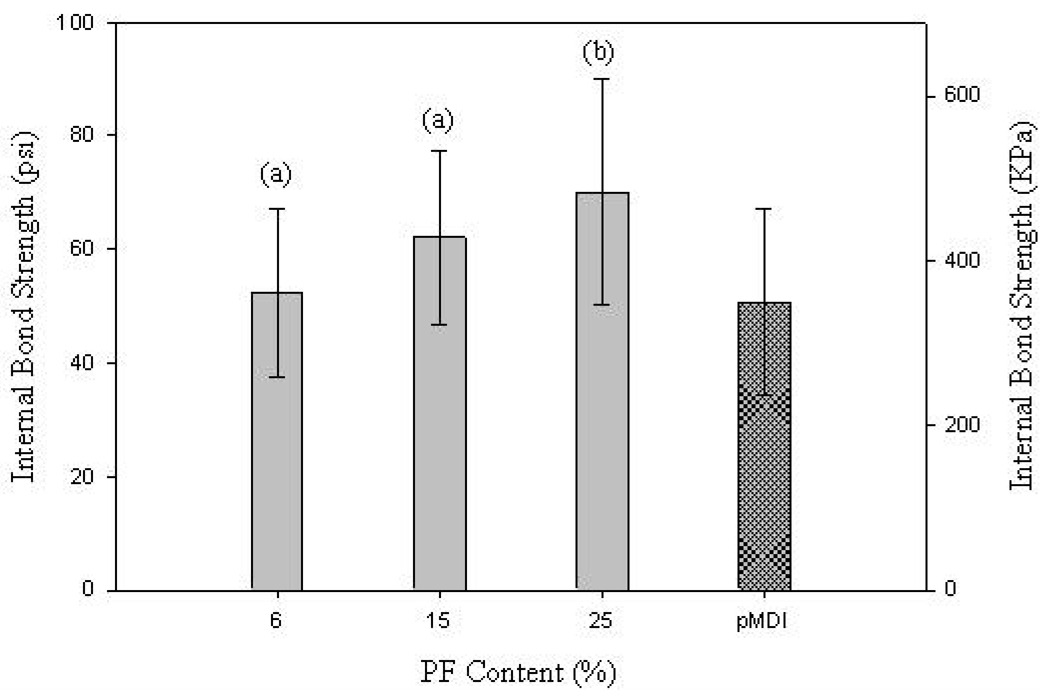

Figure 13. Change in IB strength of test specimens with varying PF levels at 6% MAPP. Average IB of specimens bonded with pMDI resin is also shown. Comparison mean test results are indicated as well.

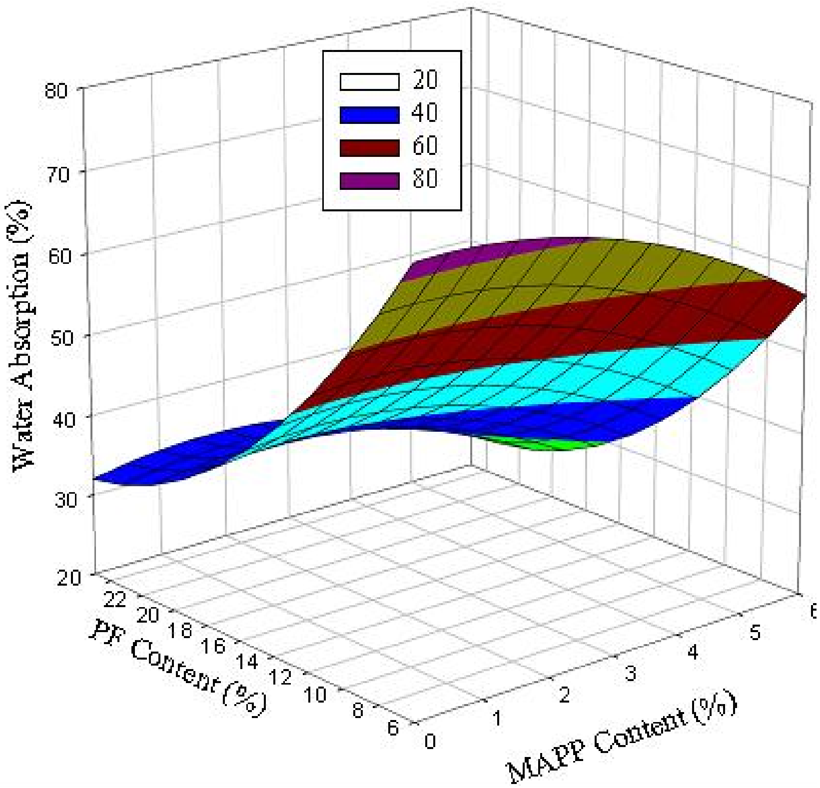

Figure 14. Response surface for water absorption for varying PF content and MAPP content for 2-hour of water soak testing.

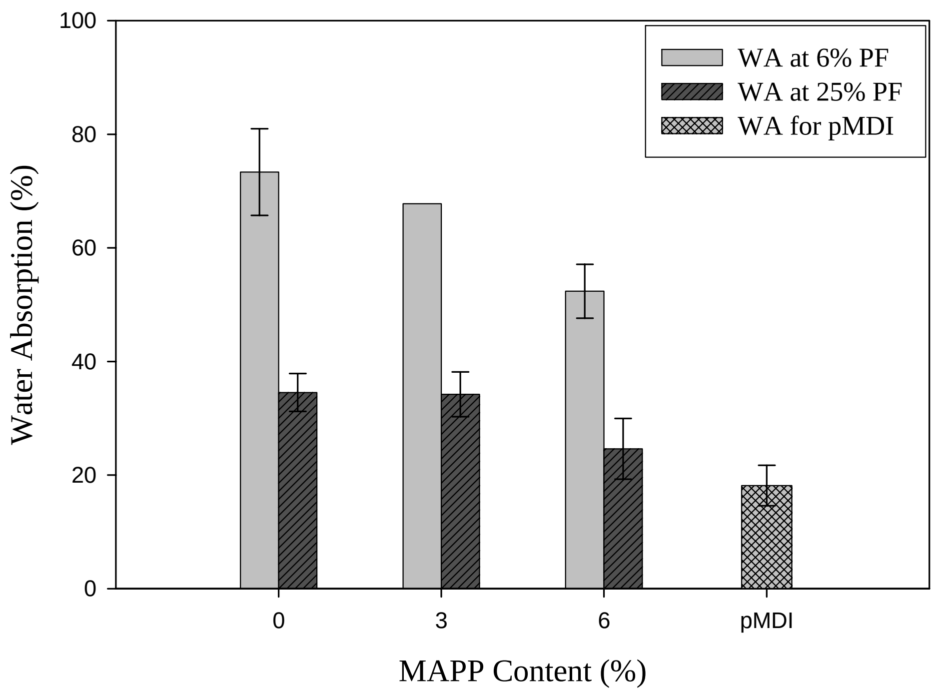

Figure 15. Comparison of 2-hour water absorption results for 6% and 25% PF content at varying MAPP content and for panels bonded with pMDI.

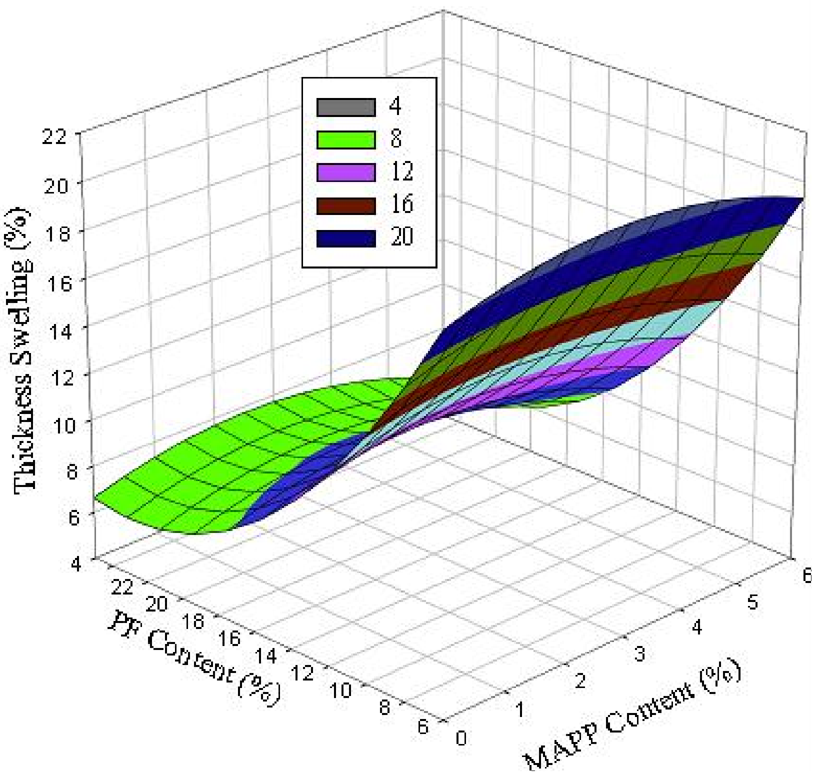

Figure 16. Response surface for 2-hour thickness swelling as MAPP content and PF content were changed.

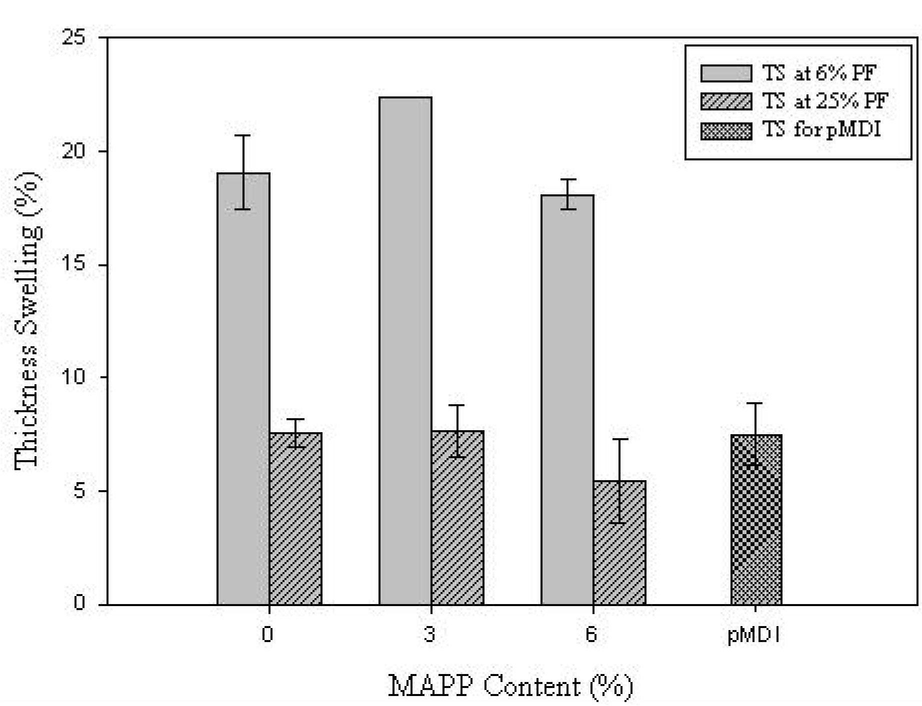

Figure 17. Comparison of 2 hours thickness swelling values for 6% and 25% PF content at varying MAPP content, compared with pMDI panels.

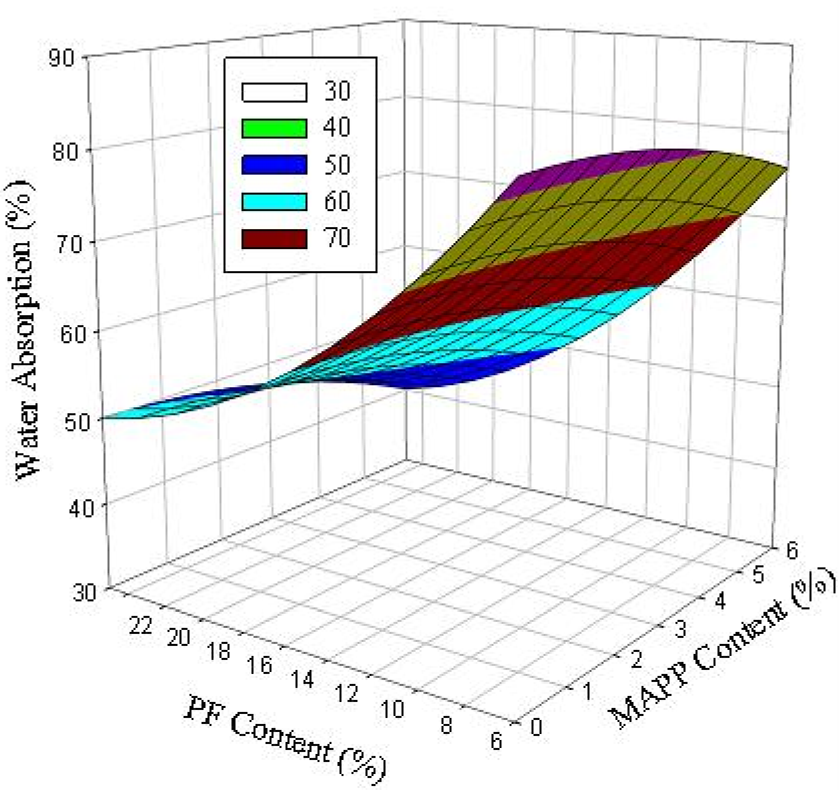

Figure 18. Change in water absorption after 24-hour water soak as MAPP and PF levels varied.

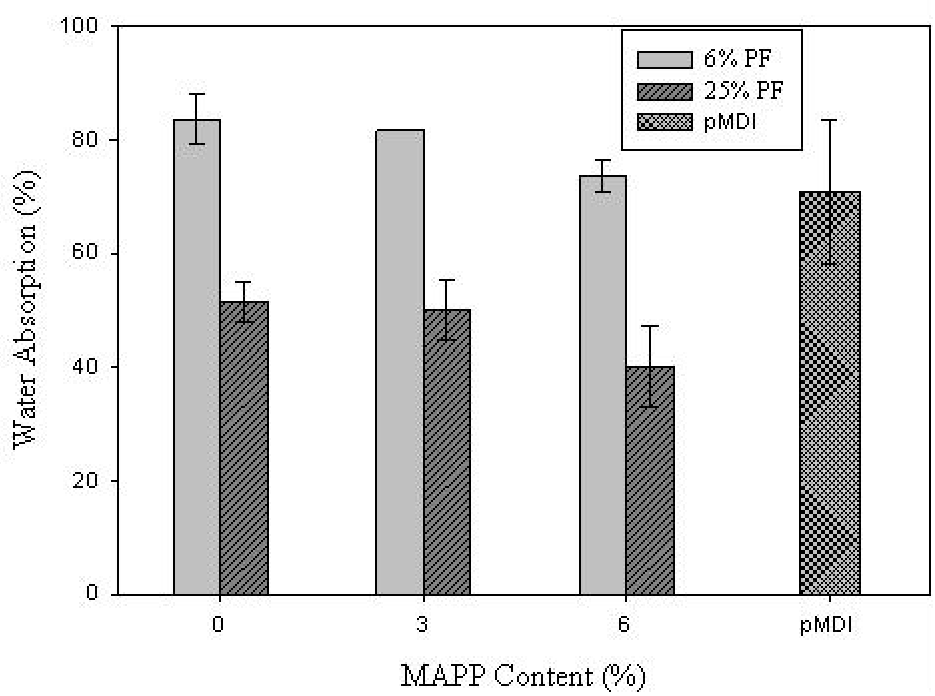

Figure 19. Comparison of water absorption after 24- hour water soak for panels with 6% and 25% PF content at varying MAPP content and for pMDI panels.

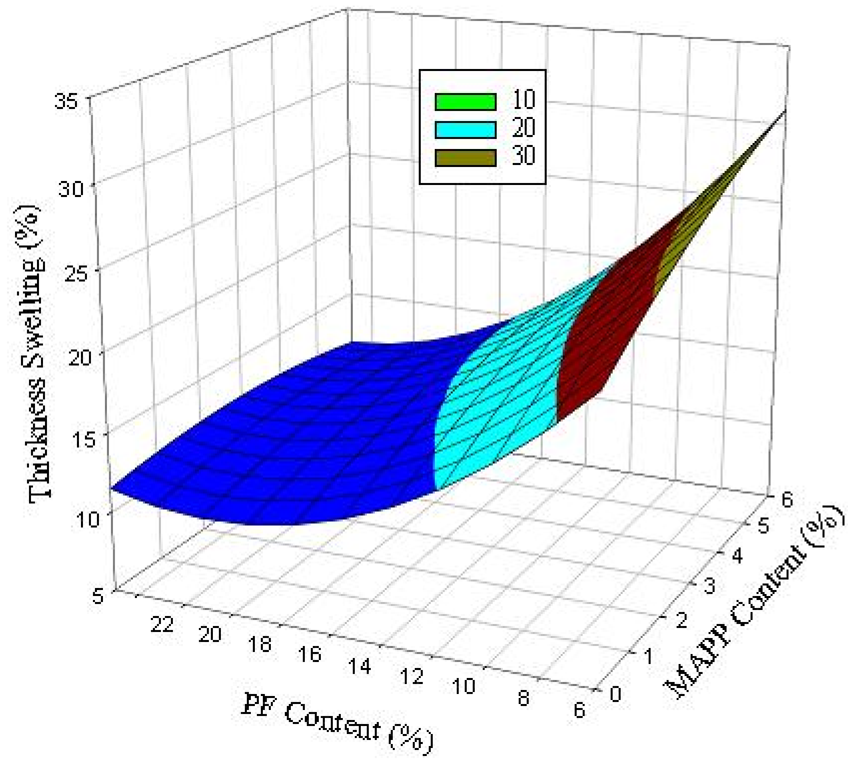

Figure 20. Changes in thickness swelling after 24-hour water soak with varying MAPP and PF contents.

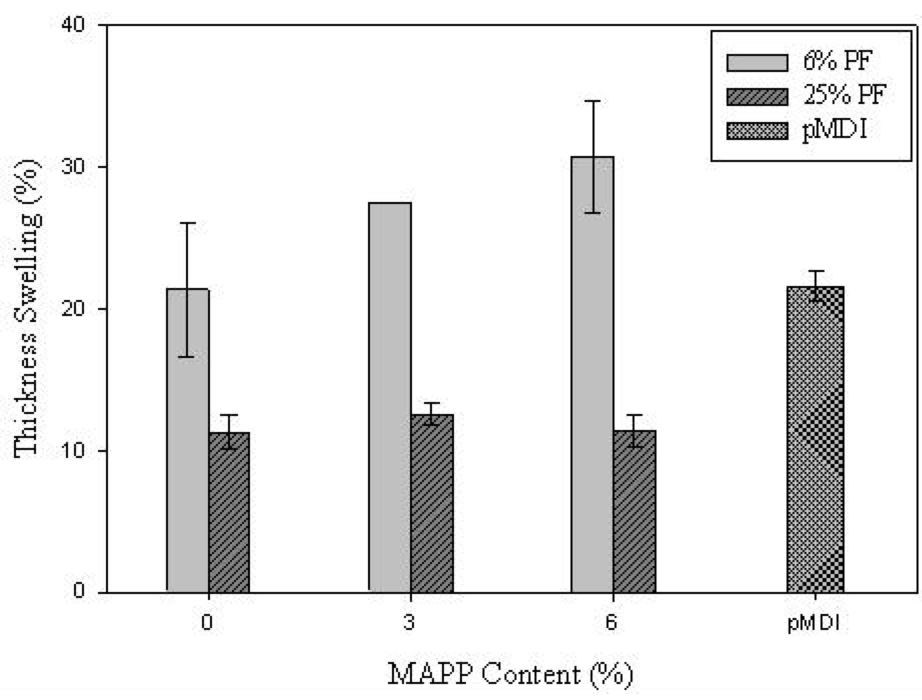

Figure 21. Comparison of thickness swelling after 24-hour water soak for 6% and 25% PF panels at varying MAPP levels and for pMDI panels.

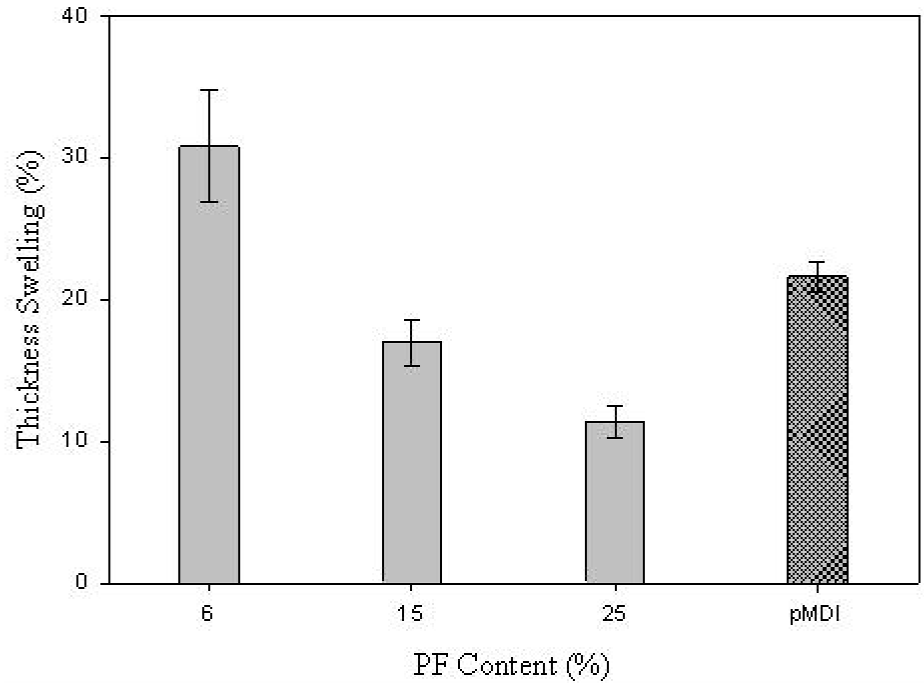

Figure 22. Comparison of thickness swelling after 24-hour water soak for panels with 6% MAPP and varying PF content and for pMDI panels.

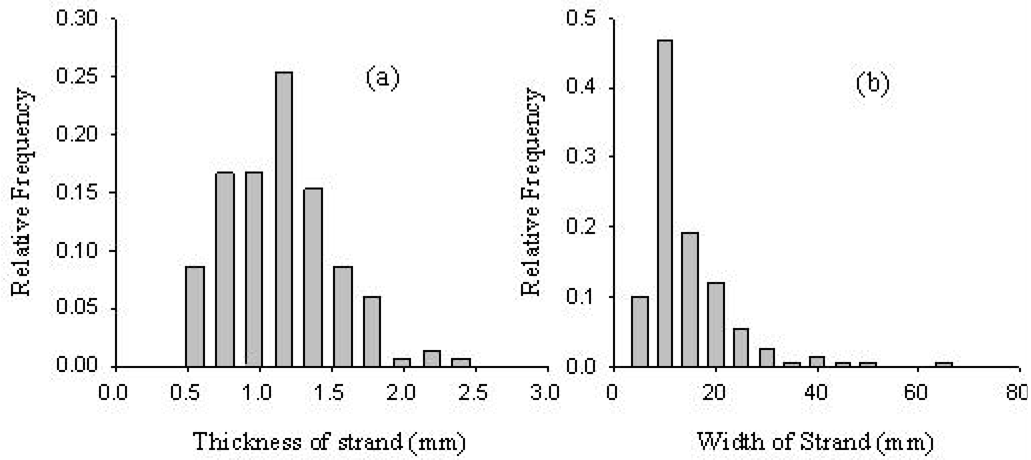

Figure 23. Distribution of (a) thickness and (b) width of the strands used to manufacture OSC test panels in this study.

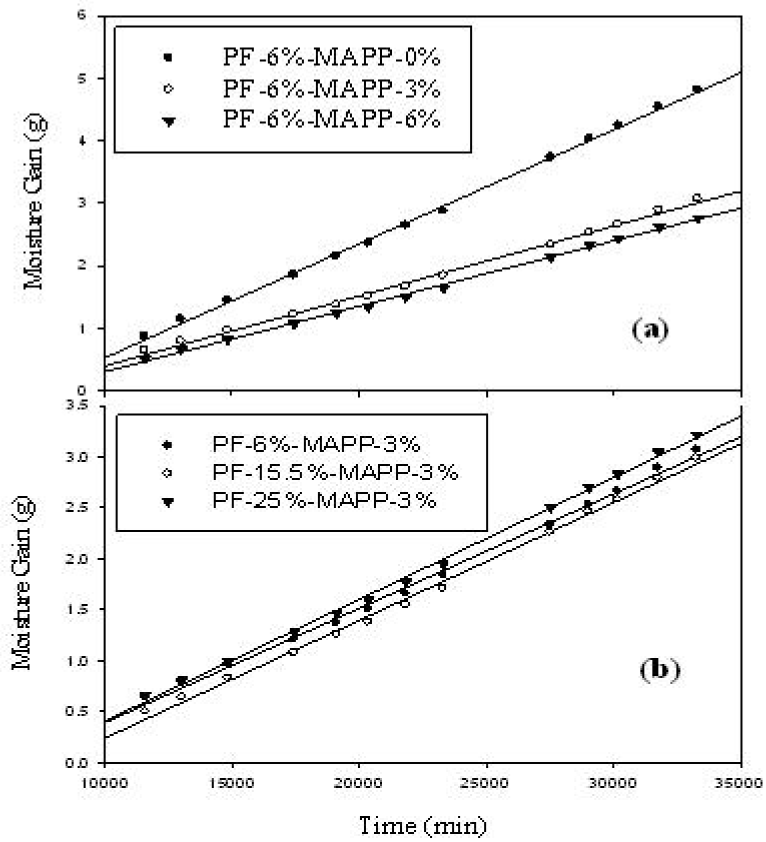

Figure 24. Typical plots of moisture gain vs. time elapsed data for diffusion coefficient specimens. (a) Slope of moisture gain for specimens with 6% PF content at varying MAPP levels. (b) Slope of moisture gain for specimens with 3% MAPP at different PF contents.

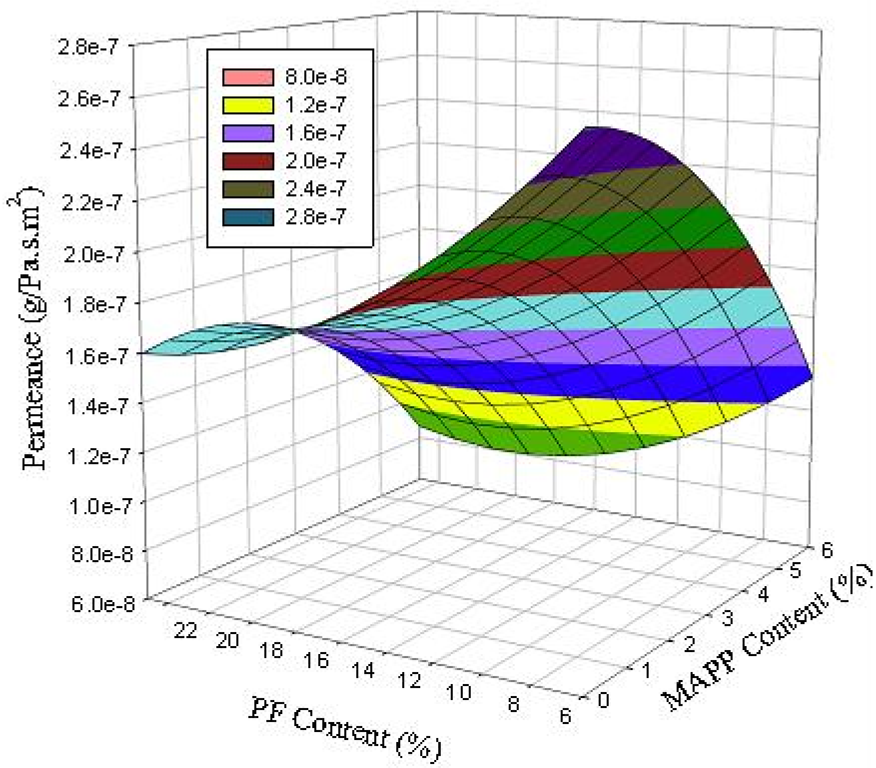

Figure 25. Response surface plot of permeance of test specimens with varying MAPP and PF content.

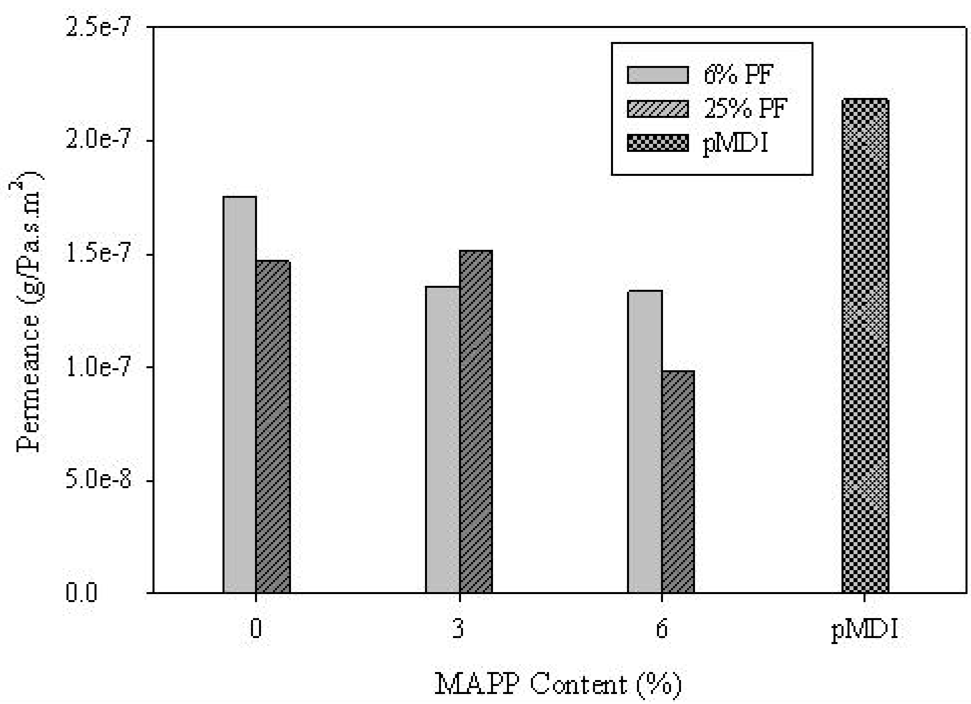

Figure 26. Comparison of permeance for 6% and 25% PF content at varying MAPP levels. Included also is the average permeance of pMDI panels.

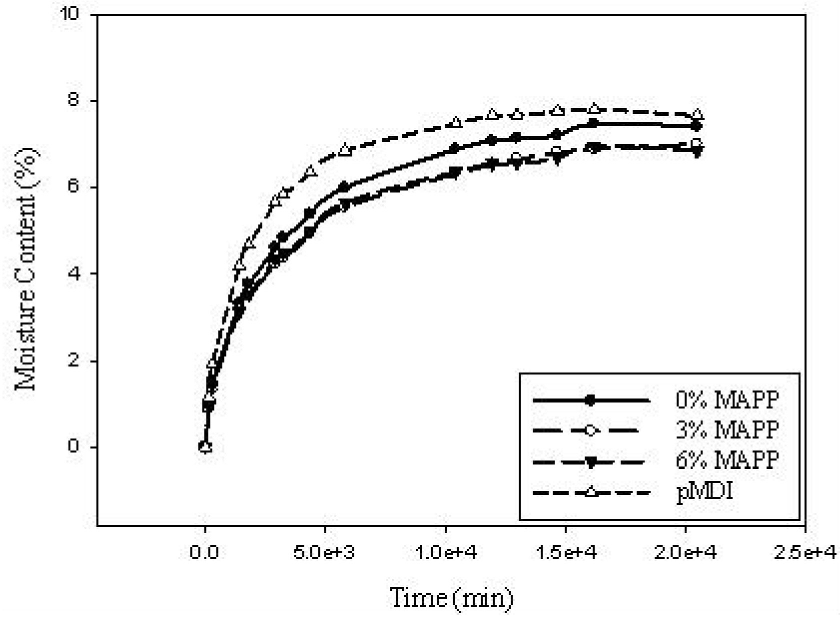

Figure 27. Moisture content gain of 6% PF content panels with varying MAPP content compared with moisture content gain of pMDI panel at 50% RH.

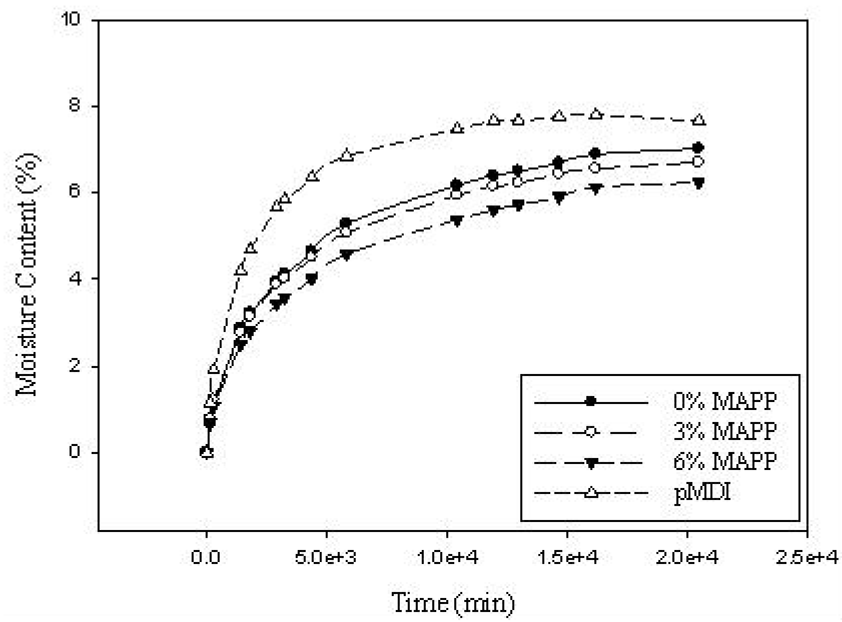

Figure 28. Moisture weight gain as a function of time for panels bonded with 25% PF content with varying MAPP levels and pMDI resin panel at 50% RH.

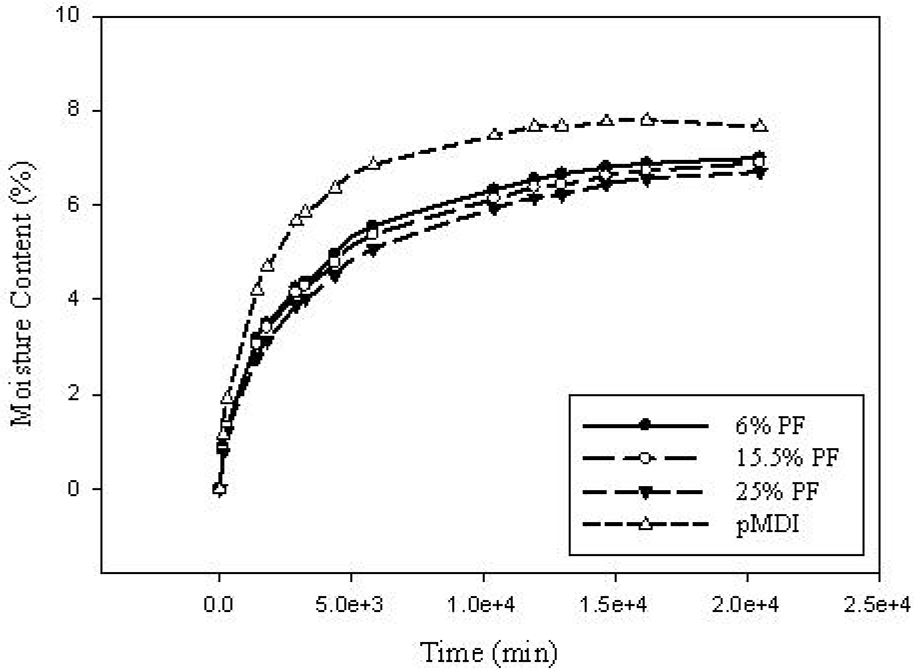

Figure 29. Moisture weight gain of test panels with 3% MAPP at varying PF content. Also included are results of pMDI bonded panels.

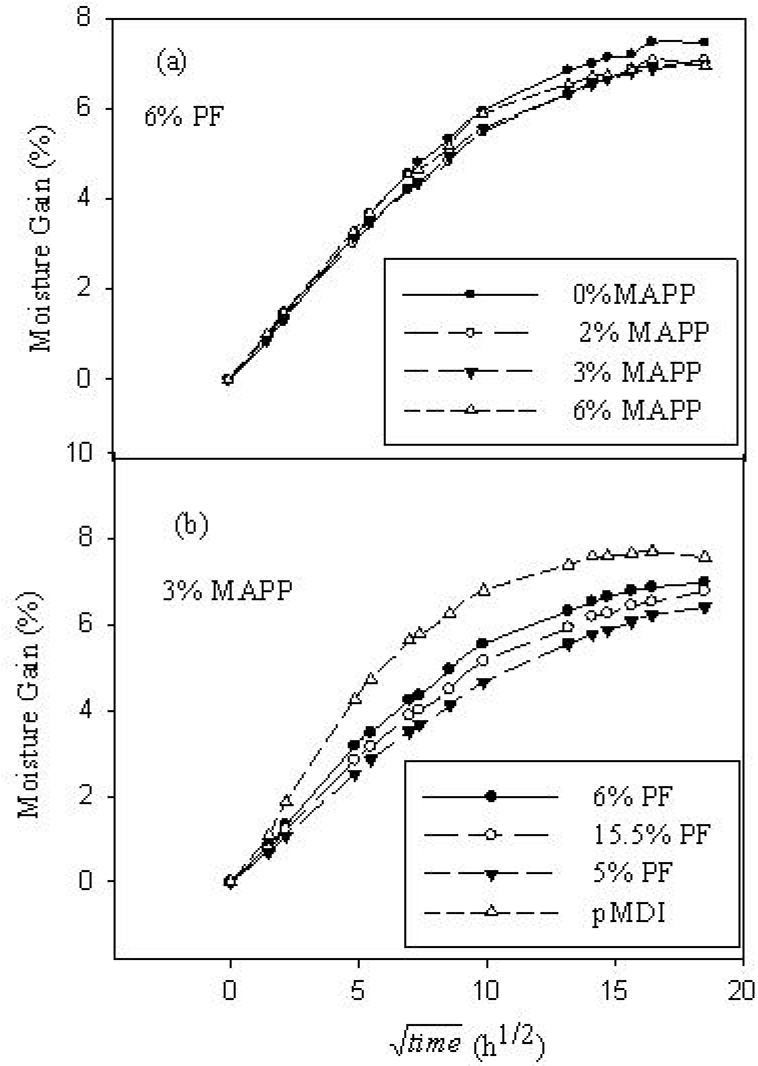

Figure 30. Typical plots of moisture gain vs. √t for determination of diffusion constant. (a) Moisture gain vs. √t for specimens with 6% PF content at different MAPP levels. (b) Moisture gain vs. √t for specimens with 3% MAPP at varying PF levels, also compared with pMDI specimen.

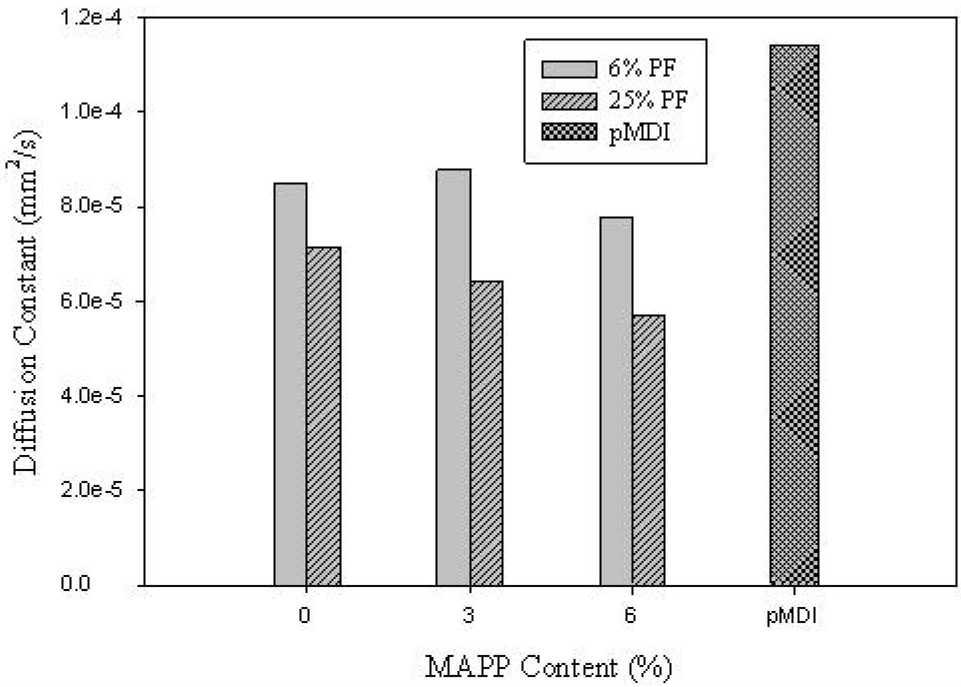

Figure 31. Comparison of diffusion constant for 6 and 25% PF content panels at varying MAPP levels after subjecting to 50% RH. Diffusion constant values for pMDI panels are also included.

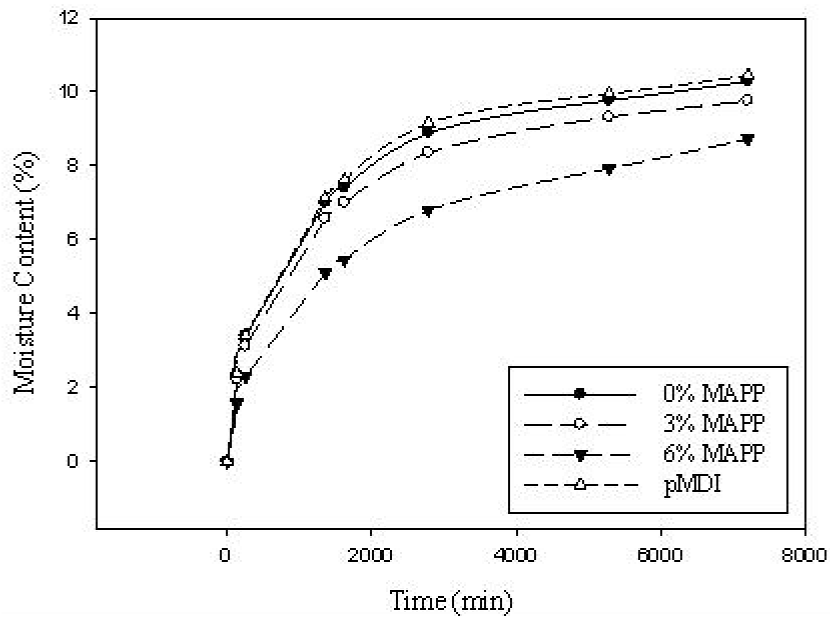

Figure 32. Moisture weight gain over time for test panels bonded with 6% PF resin at varying MAPP levels at 80% RH. Moisture weight gain of pMDI test panels is also shown.

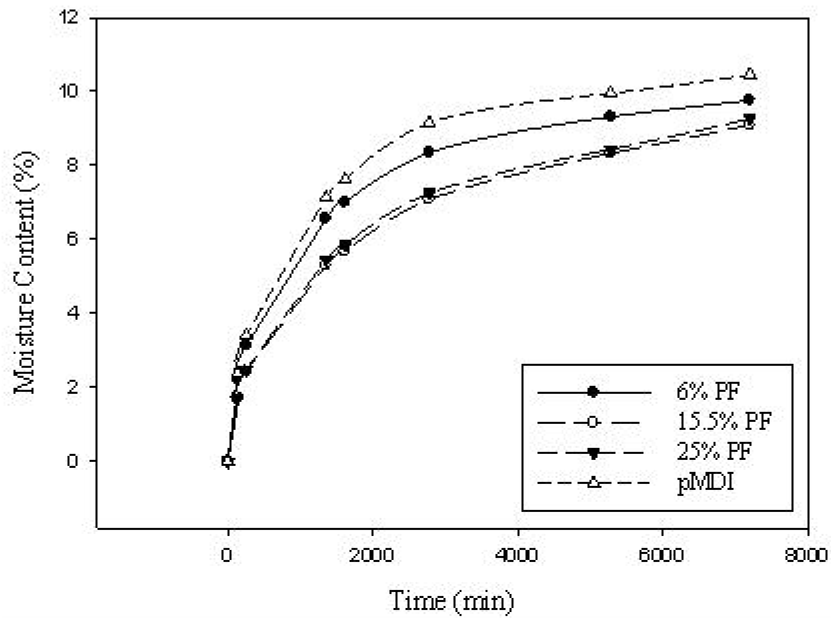

Figure 33. Moisture content gain of 3% MAPP content panels with varying PF content, compared with moisture content gain of pMDI panel at 80% RH.

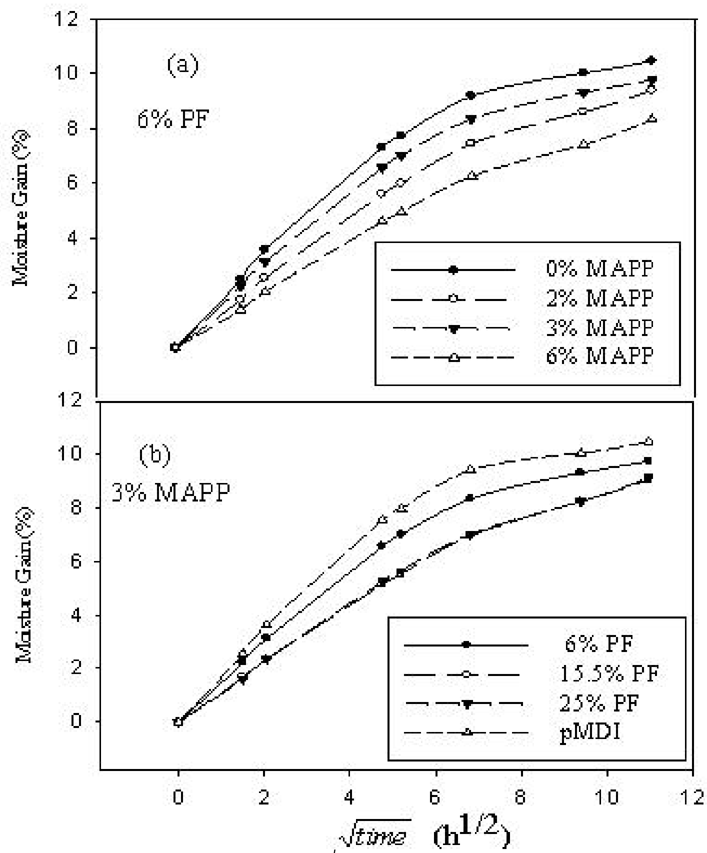

Figure 34. Typical plots of moisture gain vs. √t for determination of diffusion constant of specimens subjected to 80% RH. (a) Moisture gain vs. √t for specimens with 6% PF content at different MAPP levels. (b) Moisture gain vs. √t for specimens with 3% MAPP at varying PF levels, also compared with pMDI specimen.

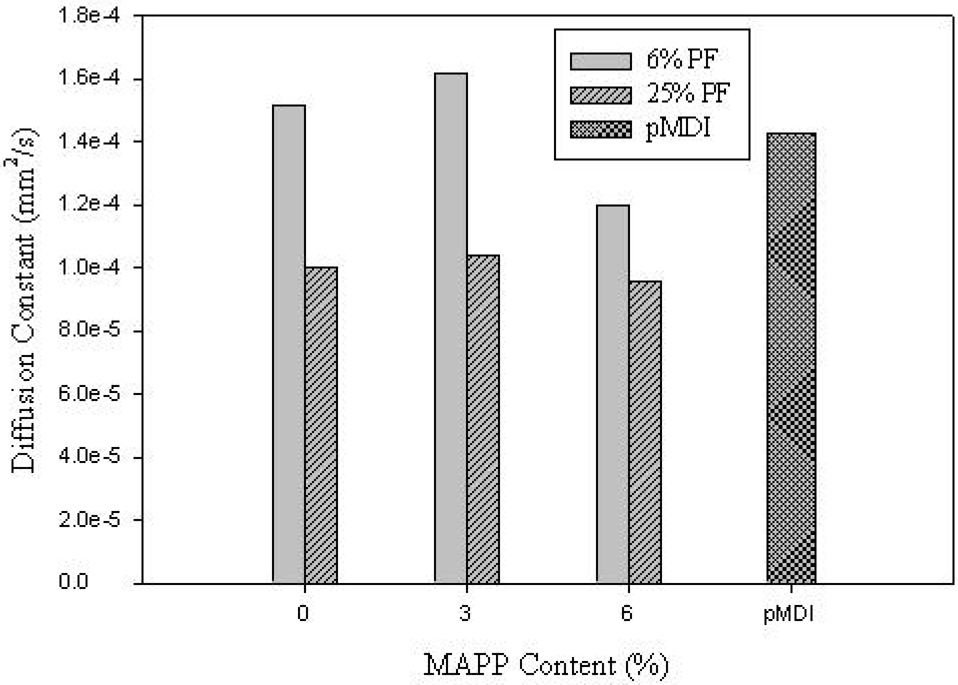

Figure 35. Comparison of diffusion constant for 6 and 25% PF content panels at varying MAPP levels after subjecting to 80% RH. Diffusion constant values for pMDI panels are also included.

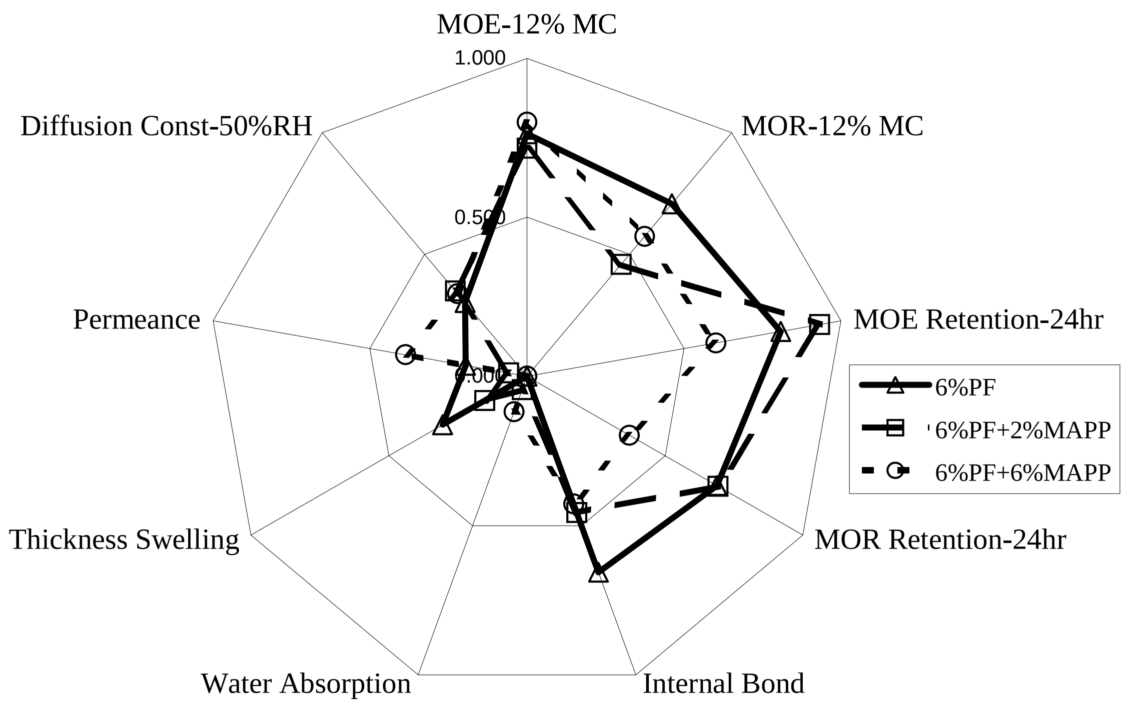

Figure 36. Comparison of properties of test panels with 6% PF content and varying levels of MAPP.

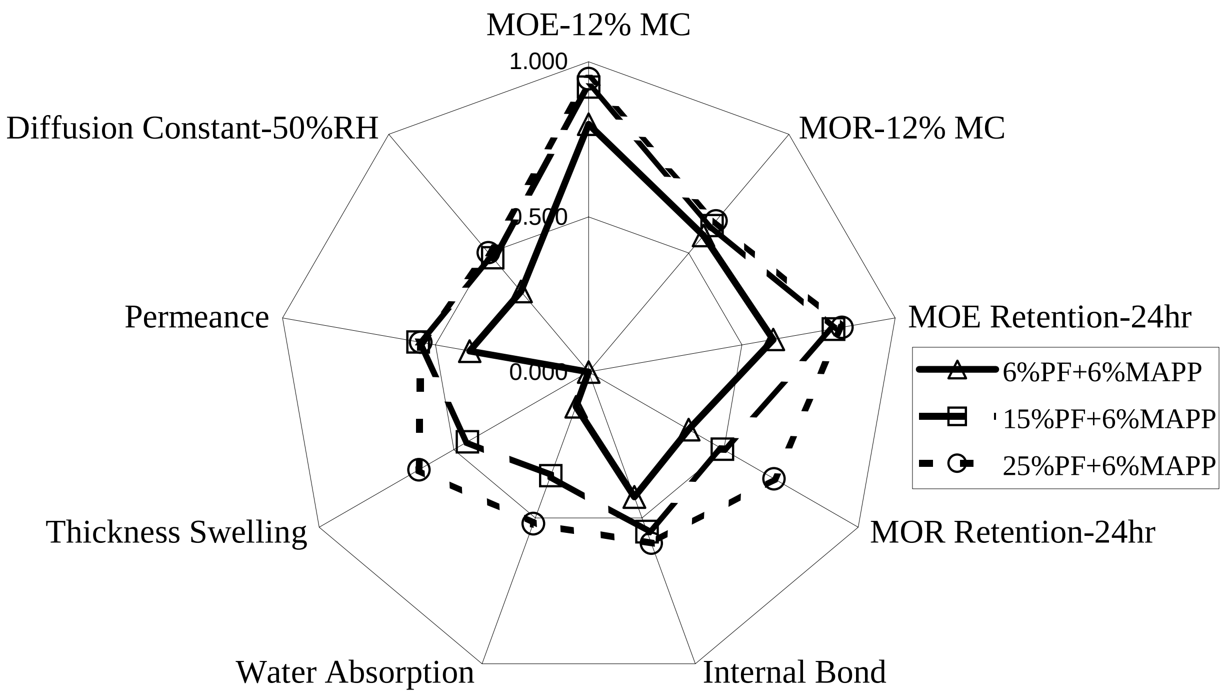

Figure 37. Comparison of properties of test panels at 6% MAPP level with varying PF contents.

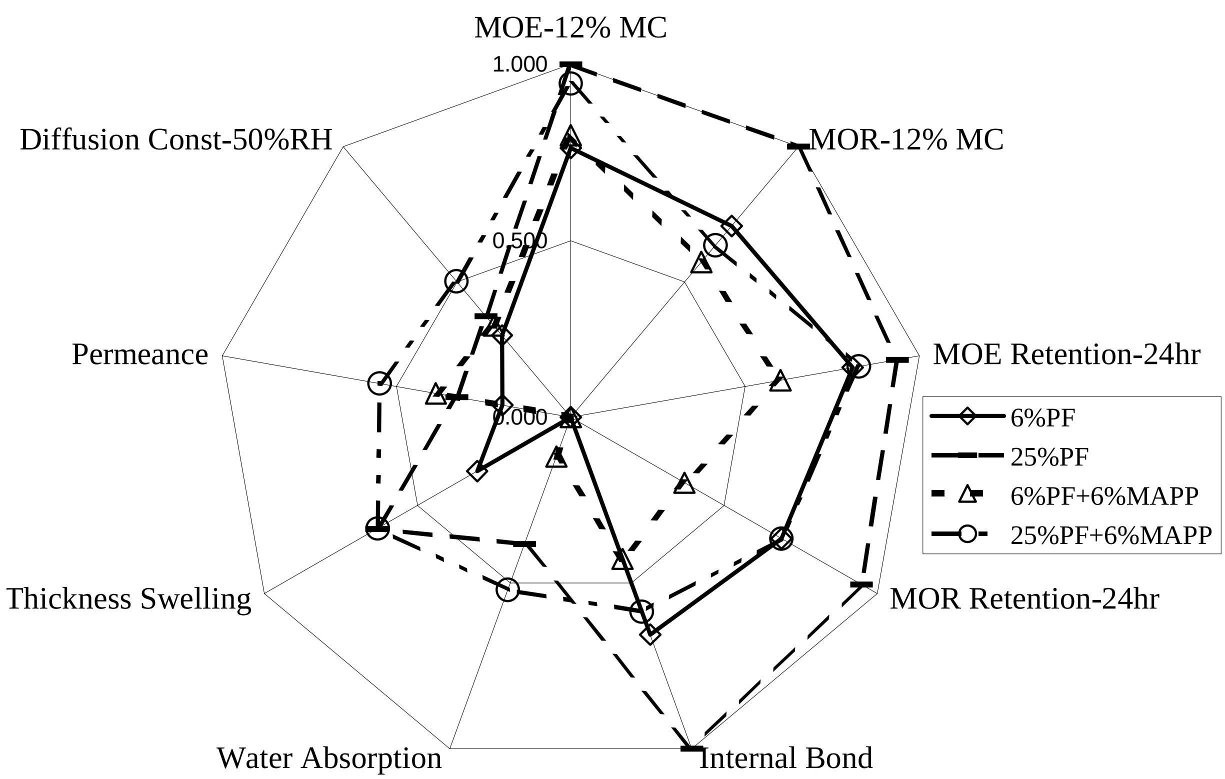

Figure 38. Comparison of properties for OSC test panels with neat 6% and 25% PF content and OSC panels with similar PF content at 6% MAPP level.

Durable Wood Composites for Naval Low-Rise Buildings

Performance of Light-Frame Wall Segments Utilizing Wood Plastic Composite Sill Plates

Integrated Sill Plate Rim Board Elements

Task C3 – Develop wood-plastic composite sill plate/rim board construction system

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Abstract

An investigation into the methods of potentially improving the performance of light-frame shear walls was undertaken as part of a larger project for the United States Office of Naval Research. The goals of the project were to increase the durability, strength, and stiffness performance of light-frame shear walls by directly substituting wood-plastic composite members for the traditional dimensional lumber sill plate. The study included connection design as well as proof of concept cyclic racking tests of full-scale wall specimens. The results showed that changing the sill plate form and the connections between the studs and the sill plate, increases the lateral capacity of the wall by a factor of 3, increases the "toughness" of the wall, and minimizes the potential for decay. Overall, the proof of concept results indicate that the potential for improving the performance of light-frame construction is significant and that if optimized, the concept could be a viable alternative to current practice and/or proprietary products.

Introduction

Wood-frame buildings incurred damage that outweighed loss by any other building type during the 1994 Northridge earthquake, in Northridge, California. Wood shear walls acting as the lateral force resisting systems were particularly susceptible to damage, exhibiting cracking at sill-foundation connections, significant deformation at wall boundaries, sliding of walls along the foundations, and longitudinal splitting of sill plates (Day, 1996). This damage, at the location where shear and overturning forces concentrate, reduces the lateral force capacity of the structure (Hamburger, 1994). Subsequent damage from failed sill-to-foundation connections under extreme loading events creates a need to understand and improve the performance of this connection.

The Consortium of Universities for Research in Earthquake Engineering (CUREE)-Caltech Woodframe Project, Task 1.4.1.1 *Anchorage of Wood-Frame Buildings,* performed extensive testing on variables affecting sill plate performance. This work completed by Mahaney and Kehoe (2002) included the following variables: sill width, sill thickness, sill species, anchor bolt size, amount of dead load, shear connection type, bolt washer size and type, anchor bolt location, anchor bolt hole size, and hold-down type. A force-controlled loading protocol based on developments in CUREE Task 1.3.2, *Cyclic Response of Wood-frame Shearwalls: Loading Protocol and Rate of Loading Effects* (Gatto and Uang, 2002), was utilized in testing specimens.

Results from CUREE anchorage tests provide insight on shear wall failure modes and ductility response. Out of sixty-three valid tests, thirty-four failed in the sill plate. Of those tests lacking hold-down connectors, where failures in the sill plate occurred, lower load capacities and lower number of cycles were achieved—compared to walls having other failure mechanisms (Mahaney and Kehoe, 2002).

Specific failures observed in sill plates occurred due to combined bending and twisting, coupled with stress concentrators along the grain from sheathing nails. By limiting sill plate bending and twisting, failure of shear walls can be shifted from brittle sill-to-foundation

connection damage to a more ductile failure associated with sheathing-to-framing connections yielding. Testing has shown that when failure modes occur in the sheathing rather than in sill plates, ductility and wall performance are improved.

Final design recommendations from CUREE Task 1.4.1.1 suggest increasing sill plate thicknesses to nominal 76 mm and using square plate washers—both design recommendations parallel code changes after Northridge earthquake. In addition, it was recommended that end studs be 102 mm nominal posts connected to stiff hold-downs, and 76 mm nominal framing be provided at sheathing panel joints.

The effectiveness of square plate washers to counteract cross-grain bending and subsequent sill splitting has been further investigated. The International Residential Building Code requires the use of plate washers with minimum dimensions of 50 mm x 50 mm x 5 mm, as opposed to round, cut washers (ICC, 2003). The American Plywood Association (APA) reported no splitting failures and shear wall strengths of 12.7 kN/m, in tests on walls with 38 mm x 89 mm sill plates restrained with large, 76 mm x 102 mm x 19 mm plate washers (Martin, 2004). Oregon State University prepared reports for the American Forest and Paper Association (AF&PA) considering different plate washer sizes for engineered shear walls (Rosowsky et al, 2004). In this testing, walls with standard round washers were shown to carry higher maximum loads with smaller deflections, resulting in lower energy dissipation than square plate washers.

Objective

For this study, development of a prototype wall-to-foundation connector system for wood light-frame walls under dynamic loading will apply specifically to slab-on-grade construction. This project utilized durable wood plastic composite (WPC) material to replace pressure-treated lumber in sill plates. Three different WPC sill prototypes were installed in full scale shear walls in order to evaluate and compare system performance of these wood light-frame walls under full-scale shear wall testing. The intent of this study is to identify specific improvements in the prototypes' structural shape, and to demonstrate a conceptual use of the durable wood-plastic material in a shear wall system versus walls constructed with traditional pressure-treated wood sills.

Methods and Materials

Sill Plate Materials

Wood plastic composite material was extruded and machined into three different section profiles, shown with nominal dimensions, along with a traditional solid wood sill in Figure 1. Sections in Figure 1 all have approximately nominal 150 mm widths. Therefore, sections will be referred to by material type and nominal depth in centimeters (e.g. WOOD4 is a wood sill plate with nominal depth of 40 mm). Section and material properties are presented in Table 1.

The solid deck board (PE3) was intended to be a direct substitution for prescriptive wood sill plates. The hollow three-box (PP5) was also intended as a direct substitution, only using a more efficient section shape. The deeper hollow section (PP10) was intended to improve upon prescriptive shear wall design, incorporating hold-down behavior between end studs and sills,

without the use of commercial hold-down fasteners. This section was developed and modified to provide the most significant improvement to traditional end-grained nailing and to reduce sill plate splitting in shear walls.

Table 1. Sill plate member properties

	Section Properties			Material Properties	
	I (cm^4)	S (cm^4)	A (cm^2)	MOR (kPa)	MOE (kPa)
WOOD4*	64.4	33.8	53.2	34,359 (35.0%)	8,513,650 (25%)
PE3	18.6	14.7	35.1	20,850 (2.4%)	3,430,149 (1.7%)
PP5	114.5	50.1	43.9	29,778 (6.8%)	4,544,211 (14.6%)
PP10	1167.9	225.7	97.5	N/A	N/A

Values in parenthesis: Associated coefficient of variation
*Based on design value of incised hem-fir, 10 minute load duration, and assumed coefficient of variation (NDS,2001)

Prototype WPC Sill Plate PP10

The designed WPC prototype sill is based on a conceptual L-shaped cross section as illustrated in Figure 2. Ideally, the bottom sill surface would be 38-mm thickness and the side section would stand 152-mm to replicate the thickness of traditional wood sills and provide additional clearance for the bottom sheathing edge, respectively. The section also provides additional connection options between studs and sills to obtain higher performance levels than rectangular sill sections. The prototype sill plate incorporates the hold-down resistance necessary for engineered design within the stud-to-sill connections.

PP10 members were machined to create slots at stud locations providing the necessary space for traditional length studs and an ability to fasten through sill side walls into stud edges. The conceptual L-section is located at stud locations and does not have dimensions exactly equal to the intended design, as the tested prototype used previously developed cross-sections. Uplift resistance was provided by the lateral resistance of fasteners installed through the sill side into the studs, perpendicular to stud lengths, improving upon traditional end nailed connections, which have negligible withdrawal/uplift resistance. Calculations based on simple mechanics' assumptions indicated that the highest stresses induced in typical sill plate loading will occur in tension perpendicular-to-extrusion direction at these connections.

The PP10 sill plate design used in shear wall tests, shown in Figure 3, was based on previous component testing by DuChateau (2005) that identified highest capacities resulting from:

- Connections having maximum edge distances,
- Connections having minimal sidewall penetrations,

- Shifted end stud configurations with dowel attachment between studs and sills, and
- Reinforcement installed between flanges and webs of WPC sections.

Specimen Fabrication

Framing for each wall specimen consisted of 50 mm x 152 mm nominal Douglas-Fir, graded No. 2, No. 1, or machine rated to 1950 F_b 1.7 E or 2100 F_b 1.8 E. All lumber was purchased at the local building supply. Each wall configuration was named a different test group based on its unique sill plate. Four different sill plate types were used for walls, each having different thicknesses due to using previously produced sections.

Framing for end studs were two 51 mm x 152 mm members nailed together with 2-16d nails 610 mm on center. Double top plates were end-nailed to studs using 2-16d common nails per stud. Studs were then end-nailed to the single bottom sill plate using 2-16d nails per stud for Test Groups WOOD4, PE3, and PP5. Holes were predrilled in the WPC slightly smaller than the nail diameter for PE3 and PP5. For PP10, connections of the end studs to the sill were made with 6 mm x 51 mm Simpson Strong Drive wood screws (SDS $^{1}/_{4}$ x 2) and A36 steel dowels as previously illustrated in the sill design. Intermediate studs in PP10 were also connected to the sills using two similar Simpson Strong-Drive wood screws.

Studs were spaced 406 mm on center, with the exception of PP10 having end studs located at 127 mm from the end of sills. In order to keep constant 2.4 m wall heights, stud length varied for each test, depending on the existing sill plate section thickness. Sheathing was connected to sill plate edges for all tests, except PP10, which had 102 mm of sheathing removed to allow the sheathing to set on the sill top edge (Figure 2).

Sheathing was applied to one side of the framing with the long dimension parallel to the studs, allowing a 3.2 mm gap at sheathing panel joints for all walls, and also at the bottom edge in PP10. Sheathing was 11 mm OSB, Exposure 1 rated sheathing attached with pneumatically driven 8d common nails, with 76 mm on center edge nailing and 305 mm on center field nailing on intermediate studs, providing ASD shear design capacity of 7.2 kN/m (AF&PA, 2001). PP10 walls did not have edge nailing along the bottom of the sheathing since blocking was not used.

Anchor bolts for WOOD4, PE3, and PP5 were placed 305 mm and 914 mm from each sill plate end. Due to PP10's end stud location, the location of anchor bolts was altered as compared to traditional wall design. The locations of these bolts, which transfer both shear and uplift to the foundation, were 38 mm and 610 mm from the end of sills. For all tests, anchor bolts were 16 mm diameter, Grade 8 steel. Steel plate washers, with dimensions 51 mm x 51 mm x 6 mm, were used for all bolts.

End stud slots were cut to 80 mm width and intermediate slots at 40 mm width to accommodate 76 mm and 38 mm nominal width studs, respectively. Holes for Simpson Strong Drive screws were predrilled to 6 mm for WPC material and 4 mm for wood. Holes for 13 mm dowels in end studs were 14 mm. Anchor bolt holes had no over-drilling for WOOD4, had 1.6 mm over-drilling for PE3 and PP5 and had 3 mm over-drilling for PP10. Additional details of the wall specimen construction are presented in DuChateau (2005).

Testing Procedure

Monotonic tests followed ASTM E564 (2000), loading walls at 15 mm/min. One monotonic test was performed for each test group to determine the reference displacement for the following cyclic test patterns. Test methods were altered to apply a constant displacement rate until failure (80% peak load capacity), eliminating sequences of loading and unloading as directly specified in the standard.

Cyclic tests followed ASTM E2126-02a S*tandard test methods for cyclic (reversed) load test for shear resistance of framed walls for buildings* (2002), following the CUREE-Caltech Standard Protocol (CUREE). Two cyclic tests were completed for each test group, and the details of the test fixture and boundary conditions are presented in DuChateau (2005).

Results

Monotonic Results

Monotonic results for all test groups are presented in Figure 4. WOOD4-M, PE3, and PP5 all exhibited rigid body rotation with sheathing and studs "unzipping" from the sill plate. The sill plate developed a longitudinal split along the length for WOOD4-M, where as PE3 and PP5 failed in flexure at the anchor bolt locations. PP5 exhibited brittle behavior and developed a longitudinal split along its processing strands in addition to the flexural failure. PP10 exhibited more racking behavior than the previous three shear wall types and failed in flexural at the end stud location. Dowels used to transfer the uplift force from the end stud to the sill plate yielded before sill failure. All shear walls with WPC sill plates had sheathing fasteners that either bent (PE3) or tore through the sheathing or sill (PE3, PP5, PP10). The shear wall with the wood sill was unable to stress the sheathing connectors as the sill plate failure occurred first.

Based on the monotonic performance parameters summarized in Table 2, composite sill plates proved to be competitive with traditional treated-wood sill plate behavior. Compared to traditional wood walls, load capacities at peak and failure increased for Tests PP5-M and PP10-M. Consequently, peak shear capacities increased, upon which wall design values are established. Test PP10-M reaches an ultimate shear capacity of 9.7 kN/m, while a traditional wood wall without hold-down restraint reaches only 5.2 kN/m. For Test PP10-M, this equates to an ASD design capacity of 3.2 kN/m when assuming a factor of safety of three between ultimate and design. This would place the performance on the lower end of engineered wall unit shear capacities from the NDS, but it also is almost double the value observed for the prescriptive configuration for light-frame construction. Comparing to previous shear wall testing using the information in Table 2, the capacity attained in wall PP10-M is close in value to those walls with full anchorage tested by Salenikovich (2000) but with lower deflection capacities and stiffness.

Table 2. Monotonic test performance parameter summary.

Test ID	Load (kN)			Deflection (mm)			D_0 (mm/ mm)	k_e (kN/ mm)	E (kN- mm)	V_{peak} (kN/m)	Δ_{ref} (mm)
	Yield	Peak	Fail	Yield	Peak	Fail					
WOOD4-M	11.2	12.7	10.1	11	32	63	5.98	1.07	643.2	5.2	41
PE3-M	10.4	11.7	9.4	7	21	56	8.39	1.57	548.4	4.8	35
PP5-M	13.3	15.8	12.7	8	17	24	2.92	1.59	268.4	6.5	18
PP10-M	21.1	23.5	18.8	23	54	55	2.42	0.93	923.7	9.7	36
Salenikovich (2000)		24.2			73	107		1.6			

Top wall displacement measures account for lateral displacement due to uplift racking combined. The latter may be estimated by subtracting the measured tension chord uplift displacement from total wall top displacement to remove the rigid body motion deflection. Comparing this measure versus wall displacement in Figure 5, it can be concluded that Test PP10-M exhibits substantially more racking movement, which increases at a linear rate. This is consistent with damage observations unique to Test PP10-M, having more sheathing fasteners yielded and visible sheathing movement relative to studs. The majority of top wall displacement for Tests WOOD4-M, PE3-M, and PP5-M were due to uplift of wall ends causing rigid body rotation. The deformation pattern of Specimen PP10-M is more desirable, as it results in a more distributed damage pattern by activating more of the structure and increases the damping effects of the system when cyclic loading occurs.

Cyclic Results

A summary of average cyclic test performance parameters is presented in Table 3. Similar to monotonic tests, the first three wall types (WOOD4-M, PE3, PP5) exhibited primarily rigid body motion under cyclic loading. WOOD4 failed when the sill split along the grain. Nail withdrawal was restricted to the bottom row of fasteners between the sheathing and the sill plate. PE3 failed in flexural as the sill was lifted at each stud connection and restrained at the anchor bolts. The amount of nail withdrawal was greater than WOOD4, but still restricted to the bottom row of fasteners between the sheathing and the sill plate. PP5 exhibited brittle failure from longitudinal splitting of the sill plate, followed by flexural failure at the anchor bolt locations. Cross-grain bending was still apparent in this composite sill behavior. PP10 exhibited the most racking deformation, as represented by the increase in sheathing fastener damage distribution. Nails withdrew for the bottom 25% of the side row of fasteners. Instances of nail fatigue and fracture were observed. Dowels connecting the end studs to the sill yielded substantially and preceded flexural failure of the sill plate at the end stud slots.

Table 3 Cyclic wall performance parameters

Average Values for Wall Type	*WOOD4*	*PE3*	*PP5*	*PP10*	
Area Under Curve	416	346	303	1748	*kN-mm*
Area Enclosed by Hysteresis	2420	1602	1532	6398	*kN-mm*
Maximum absolute load, P_{peak}	10.8	11.9	16.9	28.6	*kN*
Maximum absolute displacement, Δ_{peak}	29	20	20	44	*mm*
Failure Load, 0.80*P_{peak}	8.6	9.5	13.5	22.9	*kN*
Ultimate Displacement, cyclic, Δ_u	45	35	25	77	*mm*
0.40*P_{peak}	4.3	4.7	6.8	11.4	*kN*
Displacement, $\Delta_{0.4peak}$	2	3	4	9	*mm*
P_{yield}	10.0	10.9	14.7	26.2	*kN*
Yield Displacement, cyclic, Δ_{yield}	5	7	10	21	*mm*
Shear Strength, v_{peak}	4.4	4.9	6.9	11.7	*kN/m*
Secant Shear Modulus, G' @ 0.4P_{peak}	1.8	1.5	1.5	1.2	*kN/mm*
Secant Shear Modulus, G' @ P_{peak}	0.4	0.6	0.9	0.6	*kN/mm*
Elastic Shear Stiffness, K_e	1.8	1.5	1.5	1.2	*kN/mm*
D, $\Delta_{peak}/\Delta_{yield}$	5.3	2.7	2.0	2.1	*mm/mm*
D_u, $\Delta_{failure}/\Delta_{yield}$	8.1	4.7	2.6	3.6	*mm/mm*
D_f, $\Delta_{failure}/\Delta_{peak}$	1.5	1.8	1.3	1.7	*mm/mm*

Sill Type Comparison

Use of a WPC material as a sill plate can improve the shear wall performance under lateral loads. The following discussion compares the performance of various wall configurations based upon observed failure mechanisms and calculated performance parameters. For a visual comparison, each test group had a best fit line drawn through average envelopes from individual tests, and the resulting average curves are shown in Figure 6. Wall capacities were conservative as applied dead load in service and adjacent corner elements would improve capacity, along with the ability of top and bottom panel edges to bear on adjacent walls. Similar conclusions were reached by Heine (1997) and Rose (1998), respectively, when they reviewed test results for traditionally framed walls.

Cyclic test results of walls with a solid polyethylene sill plate may be compared to that of traditional walls with treated-wood sill plates in WOOD4. Similar loads, and therefore shear strengths (10% increase for WPC), were achieved. Though with a combination of increased yield displacement (40%), decreased maximum and ultimate displacements, and decreased elastic shear stiffness, the wall ductility of the WPC was reduced when compared to walls with wood sill plates. Attributable to lowered displacement capacities, energy dissipation from cycles up to failure decreased by almost 40% for walls with a polyethylene WPC sill. Use of this WPC section could potentially have a larger improvement in performance if an equivalent thickness to 38-mm (nominal 2x) wood sill plates were used, due to the associated increase in flexural resistance when compare to the thinner sill plate used in these tests.

PP5 test results show improved load capacities--50% over that of WOOD4 walls. Similar to PE3 improvements, yield displacements of PP5 walls increased by at least 50%, consequently, lowering elastic stiffness. With a decrease in maximum and ultimate displacements due to more brittle failures, the ductility was reduced tremendously. As expected from such brittle failure, energy dissipation decreased by 40%. Despite these disadvantages on earthquake performance, walls with the three-box polypropylene section were able to provide over 50% more shear strength than the traditional wood sill plate, which would be beneficial for resisting high wind loads. To capitalize on this wall configuration's improved shear strength, weaknesses in the perpendicular-to-extrusion direction in the section must be addressed to provide desirable earthquake performance. Surface reinforcement, section profile changes, or elimination of die stranding could be viable options to improve upon sill plate behavior.

The best wall configuration when the performance parameters are compared was PP10. This is the sill plate that took advantage of changing the sill plate to stud connection from the end-grain nailing to lateral resistance. As shown in Table 3, walls with this configuration were almost three times as strong as the walls with wood sill plates. However, these walls also had the lowest secant modulus, which would translate into higher levels of damage at low loads. This low shear modulus was primarily due to two specific details, the lack of fit in the end stud connection and the missing fasteners between the sheathing and the sill plate. If the design of this sill plate were to be optimized to allow the sheathing to be fastened directly to the sill plate, the stiffness and strength would significantly increase over these test results. PP10 sill plates also provided over 50 percent more displacement capacity than the traditional wood sill plate configuration, which translates into significantly more "toughness" and safety to the wall performance.

Conclusions

Tests have demonstrated the effect of using durable wood plastic composites as a structural member in full-scale wood shear walls. Failure modes and performance parameters were compared to identify effects on wall behavior from various sill plate configurations. By achieving results comparable to fully restrained shear walls, WPC material has been shown as a viable option to effectively improve wood light-frame construction subjected to dynamic loading such as earthquakes. The following conclusions highlight each WPC section's distinguishing behavior and performance implications.

- Solid polyethylene sill plates proved to be feasible as substitutes for walls with traditional wood sill plates without hold-downs. Section integrity relies on flexural strength of the sill plate and nail pull-through resistance of the sheathing.
- A polypropylene three-box section requires section improvement to avoid brittle splitting behavior and widespread damage before being fully utilized as a sill plate in cyclic applications. Improvements can be made by eliminating strands, increasing wall dimensions, or applying exterior reinforcement.
- A polypropylene 102-mm x 152-mm (4x6) hollow section (PP10) engaged all of the wall elements, exhibiting racking behavior and achieving a design shear capacity of 3.2 kN/m (220 plf) from monotonic loading, which makes the load capacity equal to the lower

strength wood light-frame walls designed according to the NDS. This load capacity essentially doubles the strength of prescriptive construction. Racking deformations doubled compared to all other WPC sill plate and wood sill plate walls. From this improved load distribution, loads and displacements increased (load capacity increased by 160% over current prescriptive construction)—having entirely different load-deflection behavior than previous wall configurations. Consequently, energy dissipation more than doubled over traditional wood sill wall configurations. Section integrity relied on flexural resistance at end stud locations, as well as strength perpendicular-to-extrusion. The latter could be improved with reinforcement or processing without stranding.

- Walls having WPC sill plates show improved capacities when loaded under cyclic loading versus monotonic (up to and additional 20% increase in peak capacity for PP10). This is due to the different load distribution among sheathing fasteners as compared to walls with traditional wood sill plates.

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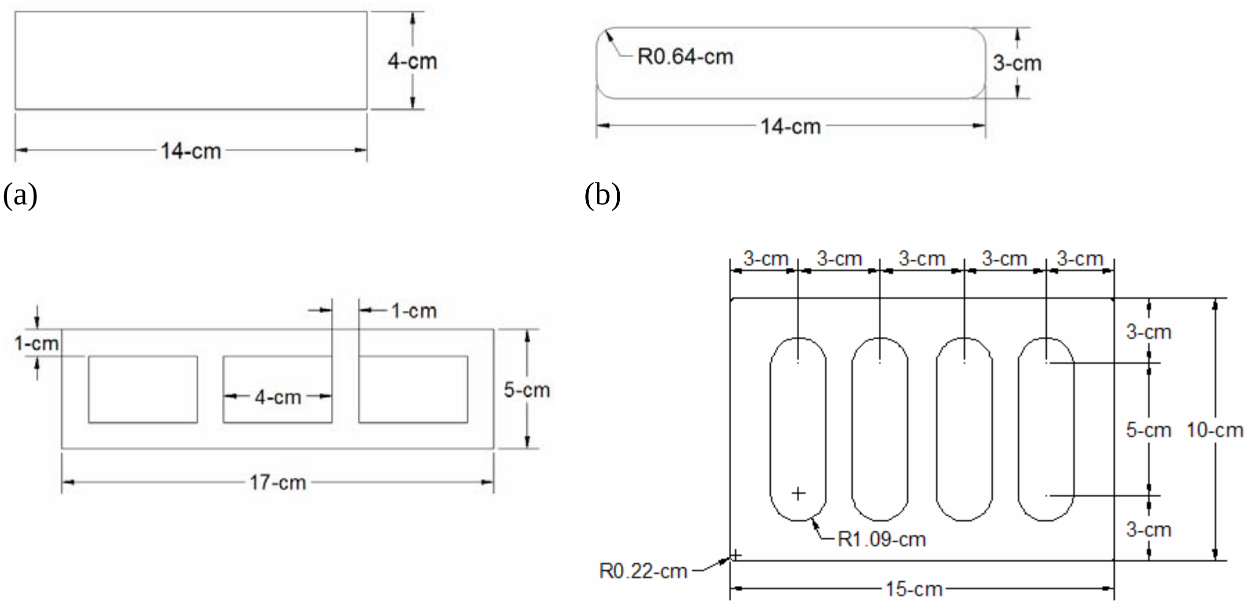
Figures



(a) (b) (c) (d)

Figure 1 Section profiles utilized for sill plates: (a) WOOD4: Pressure treated wood sill, (b) PE3: Solid polyethylene wood composite, (c) PP5: Hollow polypropylene wood composite three-box, and (d) PP10: Hollow polypropylene wood composite

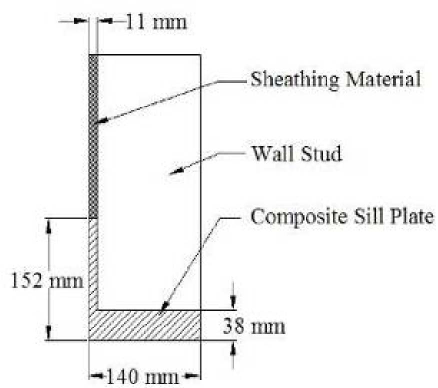
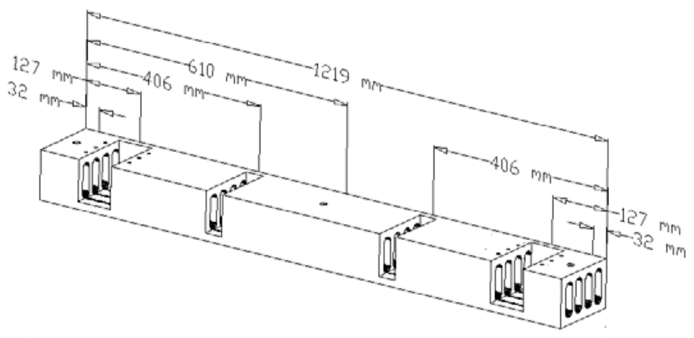
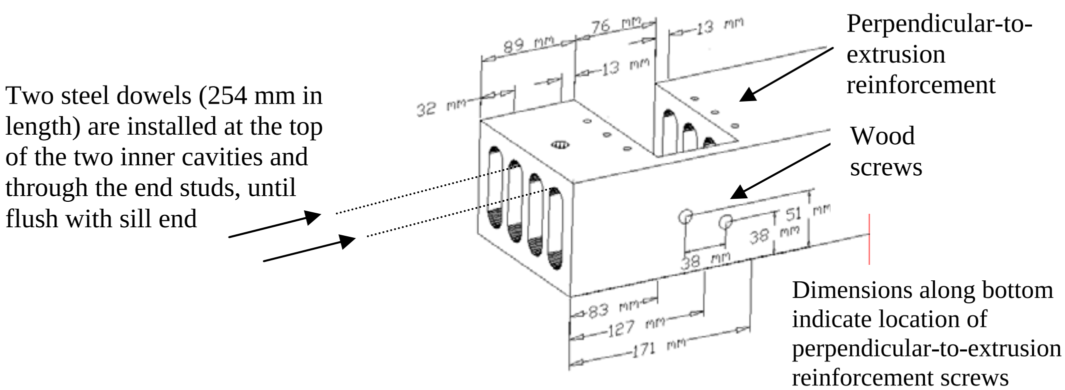


Figure 2 Conceptual sill plate



(a)



(b)

Figure 3 Component design: a) Full section, b) End stud detail

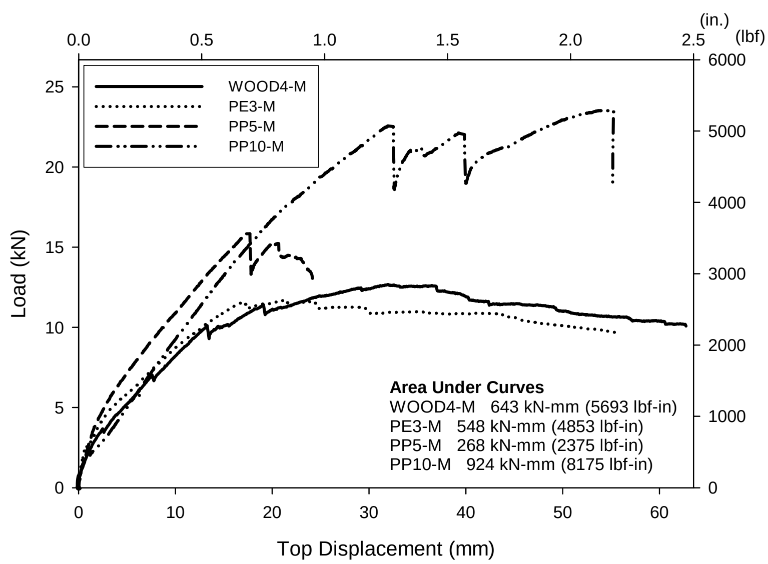


Figure 4 Load-displacement curves for monotonic tests

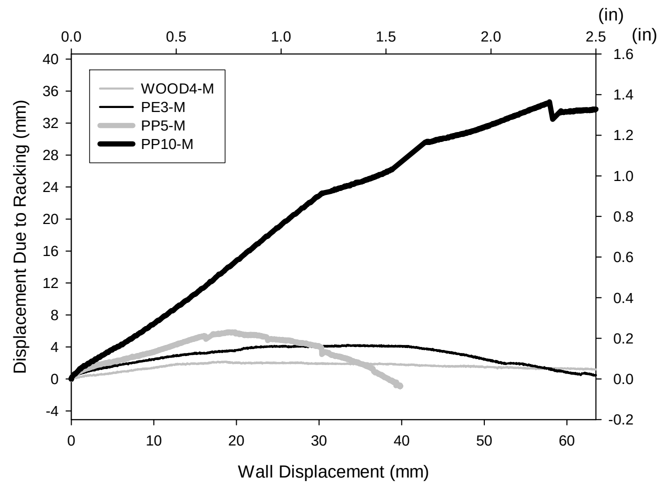


Figure 5 Racking displacement of walls in monotonic tests

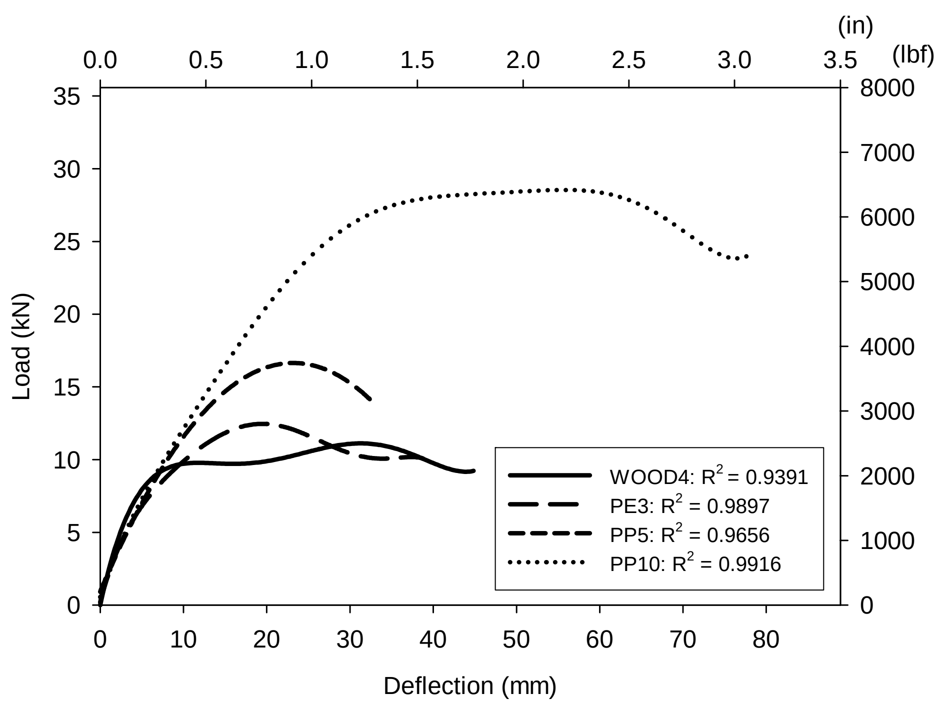


Figure 6 Best fit lines for each cyclic test group